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Preface

Wireless networks, devices and technologies play huge – and still increasing role in communications nowadays, reflecting the need for mobility and ubiquitous access. This made mobile communications the fastest growing and most profitable sector of telecommunications. Cellular networks are supplemented with fixed and satellite systems.

Rapid growth also exposes limitations of existing wireless devices and networks, driving their technical development. Additionally, other technologies required for provision of services and construction of infrastructure must be developed, too. There is a need to tackle issues like speech quality or performance limitations imposed by existing antennae and electronic devices in broadband mobile networks.

Proliferation of wireless devices brings with it the vexing problem of user safety, due to unavoidable exposure to modulated microwave radiation. Despite long and extensive research in this field, results are often inconclusive, while technical characteristics of wireless networks (frequencies used, modulation schemes, power levels, etc.) constantly evolve. More work still needs to be done, and existing regulations updated.

The emergence and development of Internet of Things reminds us also of ubiquity of Future Internet, where all electronic devices, appliances and machinery will be connected, usually without human involvement. Because of huge numbers and wide variety of connected devices, with differing needs for services, bandwidth, security level, etc., reliable object and service identification is of paramount importance here.

This issue includes papers devoted to development of wireless mobile networks and related issues: microwave propagation, broadband antenna design, prevention of stray radiation from heterodyne receivers by use of photonic rather than electronic technology, and adverse effects of microwave radiation on humans. Additional subjects include: reduction of acoustic interference in voice communications by spectral techniques, identification layer in the Internet of Things, and the more distant issue of optimization of Sudoku advisory strategy.

To begin with, the paper *Mobile Telecommunication Systems Changed the Electronic Communications and ICT Market* by A. Zieliński and K. Zieliński gives a picture how important mobile communications is, in particular in countries lacking modern fixed infrastructure like Poland. While mobile voice users have outnumbered fixed ones for over a decade, current deployment of LTE and proliferation of new terminals – smartphones and tablets is expected to make mobile operators key players in broadband access, too.

Proper operation of all radio systems depends very much on signal propagation and antennas used. J. Bogucki and E. Wielowieyska in the paper *Fading Duration in Line-of-sight Radio Links at 6 GHz* deal with issue of the first type: wave propagation which determines the performance of a radio-relay systems operating in the 6 GHz band. Such systems may be used for provision of broadband fixed access in areas lacking cable infrastructure. Signal fading is the principal factor limiting quality and availability of microwave links in this frequency band. The authors present propagation measurements performed in Poland.

In the next paper, *Dual-band Multi Slot Patch Antenna for Wireless Applications*, M. Samsuzzaman, M. T. Islam, and M. R. I. Faruque propose new design of broadband multi slot antenna for C/X bands, e.g. for use in satellite communication systems. While microstrip patch antennas are inexpensive, robust and relatively compact, the bandwidth of such devices tends to be narrow. According to simulations, the proposed multiple slot antennas can provide two separated bands, offering 970 MHz (11.96% centered at 8.11 GHz) and 890 MHz bandwidth (about 9.76% centered at 9.42 GHz), outperforming other known devices.

H. V. Baghdasaryan, T. M. Knyazyan, and M. Marciniak in their paper *High Q-factor Fabry-Perot Microresonator as an Alternative to Microdisk in Electro-Optical Modulator for Microwave-Photonic Receivers* describe a novel solution to the problem of spurious radio emissions produced by local oscillators in microwave superheterodyne receivers. The authors propose to eliminate this problem by converting microwave signals to optical frequencies (where a very effective shielding is possible), using high Q-factor Fabry-Perot microresonator as electro-optical modulator. This approach is compared with known microwave-photonic receivers employing electro-optical microdisk modulator, and claimed to be superior.

The dark side of mobile communications is reviewed by A. J. Bamisaye in a paper titled *Evaluation of Potential Dangers of Mobile Telecommunication Frequencies and Modulations*. Harmful effects of microwave radiation are particularly important because of huge numbers of persons affected, long (and rising) exposure times and systematic proliferation of new systems. Experimental studies examined effects on all levels of the human organism, ranging from single cells to reactions of entire body. The author presents recommendations for reduction of adverse health effects of electromagnetic fields encountered in mobile communication networks.

Despite growth in data services, voice services remain most popular among mobile users. For them, speech quality is important, and frequently degraded by noise coming from various sources, either a noisy environment they are surrounded by, or various devices and signal compression in the communications network they use. I. A. Alimi and M. O. Kolawole in their contribution *Enhancement of Speech Communication Technology Performance Using Adaptive-Control Factor Based Spectral Subtraction Method* look at speech enhancement by means of adaptive Multi-Band Spectral Subtraction, considered by them as the best way to deal with color (rather than white) noise encountered in real-world situations. Effectiveness of this technique was verified by simulations showing removal of colored noise without losing low amplitude speech signals and in subjective listening tests.

Internet, also mobile, is no longer for humans only. Machines and appliances use (or will use) it, too, according to the concept known as Internet of Things (IoT). In the paper *ID Layer for Internet of Things Based on Name-Oriented Networking*, J. Mongay Batalla, P. Krawiec, M. Gajewski, and K. Sienkiewicz look at the important issue of identification for this very diverse new class of users, critical for proper automatic selection of services needed. This functionality is provided by a so called ID (IDentifier) layer, exposing IoT objects and services offered by them to users. While common approach is to create the ID layer as an overlay to existing network, this paper presents a new architecture with ID layer functionality embedded into the network plane. An ID-aware network node was implemented and tested.

The last paper: *Agent-based Optimization of Advisory Strategy Parameters* written by M. Polnik, M. Kumięga, and A. Byrski is of more generalized and theoretical type, looking at application of Evolutionary Multi-agent Systems (EMAS) and its memetic version to optimization of Sudoku advisory strategy. The authors compare results obtained experimentally using EMAS and Parallel Evolutionary Algorithm (PEA) in decision support in Sudoku solving.

Hope readers will find this up-to-date content of current issue of the *Journal of Telecommunications and Information Technology* useful and interesting.

Krzysztof Borzycki
Associate Editor

Paper

Mobile Telecommunication Systems Changed the Electronic Communications and ICT Market

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Abstract—The paper covers development and importance of mobile (cellular) telecommunication services, which developed during last about 20 years and are currently the most important and profitable telecommunication sector. The development of mobile telecommunications becomes essential factor of economic growth in many countries, especially in developing countries. Currently due to the scientific and technological progress as well as the implementation a new standard known as LTE system, cellular telecommunication becomes the basic element of the modern broadband telecommunication infrastructure and internet services. Growing importance of the mobile systems is also connected with great popularity of new mobile terminals – smartphones and tablets. These terminals together with the technology known as cloud computing changed also the ICT market. The paper relates to the situation in many countries, but mainly to Poland.

Keywords—GSM cellular network, market penetration and prospects, mobile communication, services.

1. Introduction

Cellular systems are the main element of the mobile (radio) communications and have started to shape the entire development of electronic communications, including broadband Internet and electronic media.

The first cellular systems, called cellular telephony emerged in the US in the 70's and were designed for personal voice communications (telephony). In the initial stage of their development, analog systems prevailed, both in the signal processing and their transmission in free space. Those systems are called first generation systems and are marked by the symbol 1G.

In Europe in the beginning of 80's the analog system NMT 450 (Nordic Mobile Telephony) gained the widest popularity working in the frequency band 450 MHz. The system was developed in Scandinavia, mainly by the company Ericsson. NMT was accepted in 1992 in Poland and implemented by Telekomunikacja Polska affiliated company Centertel (today Orange).

In Europe in the early 80's, studies were undertaken to develop a more modern, fully digital system known under the name GSM, the acronym standing today for Global System for Mobile Communications (initially Groupe Spécial Mobile from the name of the committee initiated by CEPT in 1982). After the creation of ETSI (European Telecommunications Standards Institute), the institute continued work on GSM, establishing the European standard for this system through the issue of the system specifications in 1991. From then on the European career of GSM system started, followed by the world-wide one, making GSM the dominating standard for mobile (cellular) telecommunications in the world. The GSM system defined by the mentioned ETSI standard is called the second generation system and is marked by the symbol 2G.

In Poland the GSM age was initiated by the Minister of Communications (Post and Telecommunications) issuing in year 1996 two new GSM licenses for companies Polkomtel (market name Plus) and Polska Telefonia Cyfrowa PTC (market name Era, today T-Mobile). Later the GSM licenses were granted to companies Centertel (today Orange) and Play (initially called P4).

The new factor driving the development of cellular systems and their impact on the development of electronic communication systems is the recent emerging, during the past five years, of the new generation of cellular terminals such as smartphones and tablets. The significance of this phenomenon will be discussed later in this study.

This article is organized as follows. After short introduction presented in Section 1 development of GSM's mobile telecommunication systems through the years was described in Section 2. Section 3 presents development of the world market in the last decade by the countries ad regions. Section 4 focuses on services and new terminals and the Section 7 presents mentioned issues in Poland. Section 8 concluded an article.

2. The Development of GSM's Mobile Telecommunication Systems

The GSM system, initially developed for telephony needs, continues to include many additional services, making it the universal digital communication system encompassing in addition to voice many services, ranging from the popular SMS to data transmission, including multimedia. It shall be underlined that the GSM system, developed by the joint effort of the european countries for nearly the whole continent, became the standard worldwide. Although in the US other similar cellular systems gained popularity, the consistent joint policy of the european governments induced the worldwide success of this system.

GSM further developed its technologies to capture new frequency bands and to increase the throughput of transmission, and has remained the foundation of the subsequent system variations enlarging the range of its applications.

The GSM system, initially developed for a 900 MHz band, due to high growth of the mobile service market and the number of subscribers, was implemented in 1800 MHz band, also known as DCS 1800 (Digital Communication System in band 1800 MHz). Due to propagation reasons (shorter ranges) DCS 1800 is offered mostly in urban agglomerations, characterized by high density of population.

Soon after, in the 90's, GPRS technology (General Packet Radio Service) was developed, enabling GSM to transmit mobile data with the theoretical rate of 115 kbit/s (in practice 35 kbit/s in most applications), followed by EGPRS technology (Extended GPRS) known as EDGE (Enhanced Data for Global Evolution). GSM systems utilizing EDGE enable a data transmission rate of theoretically up to 473 kbit/s, however, most often 236.8 kbit/s. Informally GSM with such technology is sometimes called the 2.5G or even 2.75G generation of this system. At the end of the 90's another GSM enhancement called UMTS (Universal Mobile Telecommunications System) was developed, called 3G. By default UMTS allows a transmission data rate of 384 kbit/s. GSM and UMTS networks are compatible and mobile phones work as terminals for both networks.

Jointly all these developed technologies should be seen as a family of cellular systems GSM.

In the year 2000 subsequent expansions of GSM system were created, called HSPA (High Speed Packet Access) and then HSPA+, allowing for a data rate of up to 14 Mbit/s at HSPA and 28 Mbit/s at HSPA+. These are commonly referred to as the 3.5G generation of the system.

In 2008 another standard for mobile telecommunication was proposed under the name LTE (Long Term Evolution) featuring much better transmission parameters than its predecessors, most of all the transmission rate of up to 100 Mbit/s, nearly as high as in fixed line fiber optic networks. Works are in progress on a standard defined as LTE Advanced (LTEA), which is about to feature a transmission rate in the range of 1 Gbit/s. It is expected that this standard shall be accepted in 2013.

In principle the LTE system has already become a worldwide standard. In many countries, including North America (USA and Canada), Brazil, Germany, Scandinavia, Central-Eastern Europe (including Poland), the Russian Federation, India and Australia, LTE was used in commercial networks already in 2012. In China, Western Europe, Mexico and other countries LTE is in preparation for commercialization or in trials.

The international consortium 3GPP (3rd Generation Partnership Project) plays an important role in mobile standard development, gathering six standard partners from North America, Asia and Europe (ETSI). Among other 3GPP has established UMTS (IMT-2000), HSPA+, LTE and LTEA standards.

A certain variant of mobile telecommunications is the Wi-Fi standard (actually few standards of IEEE 802.11 series) designed mainly for internet access in local WLANs (Wireless Local Area Networks), working in unlicensed bands, mainly in 2.4 GHz. This technology is used by individuals for small access networks in apartments and houses, as well as entities providing internet access in public spaces – in cafes, railway stations, hotels, offices. This technique can be as well used for covering larger areas like cities or municipalities. In the US, the FCC is considering a project to build free public Wi-Fi networks practically in all cities, however, with a strong resistance from cellular network operators [1]. As for now the world-wide scale of such undertakings is still small, however, in many countries including Poland, Wi-Fi hot spot type of internet access is practiced. This technology is being further developed, however, complementarily to GSM networks.

3. Development of the World Market of Mobile Telecommunication Systems

The mentioned history of the development of the family of GSM systems clearly points out the huge and comprehensive technological progress in this realm. This progress is characterized by a quick global market growth for mobile telecommunication services along with internet services because (similarly to fixed line telephony) the mobile telephony infrastructure is successfully used to prove internet access service. That was the primary goal of the consecutive GSM system improvements, including the most recent one – LTE.

The percentage penetration of a given service is the measure of the market development of the service, most commonly understood as the number of users of the service for 100 inhabitants. The mobile telecommunication service penetration achieves worldwide impressive values, quite substantially exceeding 100, which means that the number of used terminals (SIM cards) is significantly higher than the number of citizens. The latter is qualified by various reasons, though possibly results simply from users switching from the older registered phone to smartphone.

It is worth emphasizing that the fast development of mobile telecommunications is the privilege of not only rich societies, although the penetration levels exceeding 100 occur just in those countries, but also in developing countries. Mobile telecommunication achieves significant values of service penetration because the available services exceed voice service (internet service and other services in recent development) and constitute a strong catalyst of the economic growth of those societies.

In Fig. 1, taken from statistical resources [2] of ITU (International Telecommunication Union) the history of worldwide growth of the mobile telecommunication sector during the last decade is shown, with an indication of this growth in developed countries, developing countries, and world average.

For comparison Fig. 2 presents the changes during the last decade in the penetration of the fixed line telephony, referring as previously to developed, undeveloped countries, and a world average.

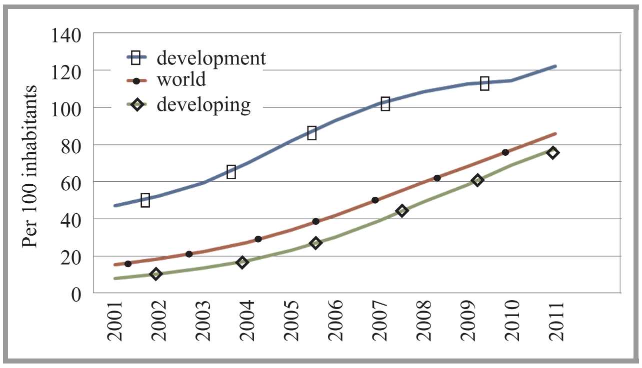

Fig. 1. Worldwide mobile penetration per 100 inhabitants in years 2001–2011.

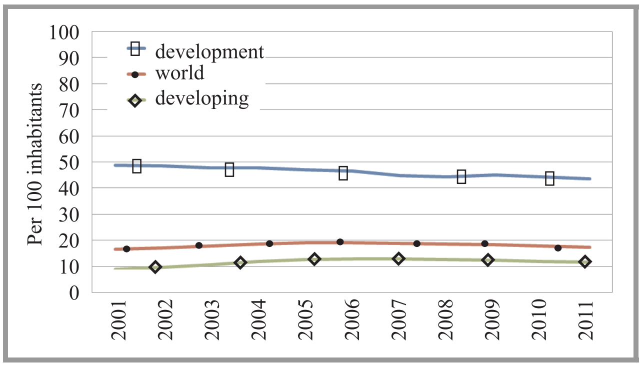

Fig. 2. Worldwide fixed line penetration per 100 inhabitants in years 2001–2011.

Obviously, during these decades the fixed line telephony services served as a foundation for the telecommunication system of the world. The market development for these services was recognized as one of the most important factors defining the economic and social prosperity of the countries having a sufficiently well-developed telecommunication network enabling to provide these services. However, as seen in Fig. 2, during decades of development the fixed line telephony has achieved no spectacular successes in widely spreading the services and developing the market for the majority of world citizens. That applies first of all to developing countries, but also to many European countries. The reasons can be identified as the very weak economic condition of the developing countries and also in many cases as an underestimation of the catalytic properties of telecommunication systems for the development of national economies.

As a result of the emergence of an alternative technology of mobile systems and networks, the situation changed in favor of the development of the new technology, which can be proven by comparing data from Fig. 1 and Fig. 2. Mobile systems turned out to be not only an efficient competition in voice services (telephony), which was the immediate reason of the decline of fixed line telephony worldwide, but also became an important transmission medium for such services as SMS, MMS and internet access.

The worldwide average decline, including developing countries, is not big, see Fig. 2. A stronger decline is observed in developed countries, which is due to a stronger dynamics of the mobile telephony development and increasing internet access through the mobile infrastructure.

These phenomena are shown in Fig. 3 with respect to few highly developed countries, including Poland, Czech Republic and China, which has to be regarded as a developed country [2].

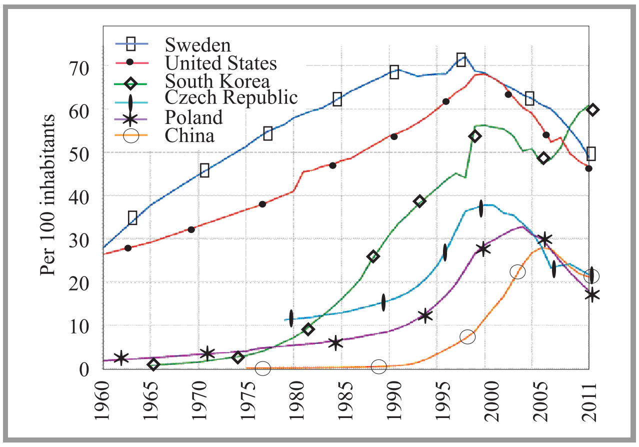

Fig. 3. Fixed line telephony penetration per 100 inhabitants in selected countries, including Poland.

The decrease in popularity of fixed line telephony can be observed nearly everywhere. However, in South Korea there is a significant growth, whereas in Poland and Czech Republic a dramatic penetration decrease can be observed, moreover in Poland it continues to deepen. Figure 3 shows an interesting regularity. The highest penetration has occurred around the turn of the century, caused by the strong growth of mobile telecommunication. In China that height was achieved around 2005, which is attributable to time-shifted economic prosperity of this country in relation to highly developed countries.

In Fig. 4, following ITU data, the mobile market development measured by the penetration ratio in few EU countries (including Poland), Asia and the USA is shown. The same information regarding Easter European countries is presented in Fig. 5. In this development scenario, Europe is particularly privileged, as the most favorable conditions were created here for the development of the common GSM standard elaborated by ETSI. In the USA, where no common standard for mobile systems was adopted, the growth ratio was lower, as shown in Fig. 3, however, at the beginning of the process, the mobile penetration in US was higher.

The position of Poland is high on this chart, showing our success in the development of this realm of electronic communication. That's a result of effective regulatory policy, assuming the competitive model of market develop-

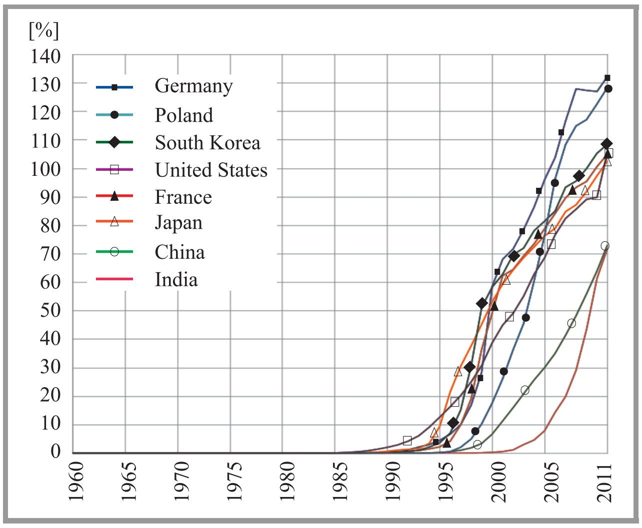

Fig. 4. Mobile telecommunication development in selected countries of EU, Asia and USA, measured by the penetration ratio.

ment from the very beginning of the development of GSM in Poland. Mobile penetration in Poland for the end of 2011 was 131.6% and is approximated at 140% for the end of 2012, taking the growth ratio into account [3]. The successes in developing mobile telecommunication in the world's most populated countries – China and India – are worth deep consideration, as they contributed to spectacular economic and civilization success in these countries.

Although the mobile penetration in both China and India has not neared 100% yet, the achieved results should be recognized as impressive, considering the high population. South Korea deserves particular attention for the consequent adoption of electronic communication systems and networks with use of the latest fixed line (fiber optics) and mobile technologies, making them the leader in utilizing internet for economic and social applications. This purpose has been served for many years by an effective economic policy of the country's government supporting development of electronic communication means and directed towards the development of a knowledge-based economy.

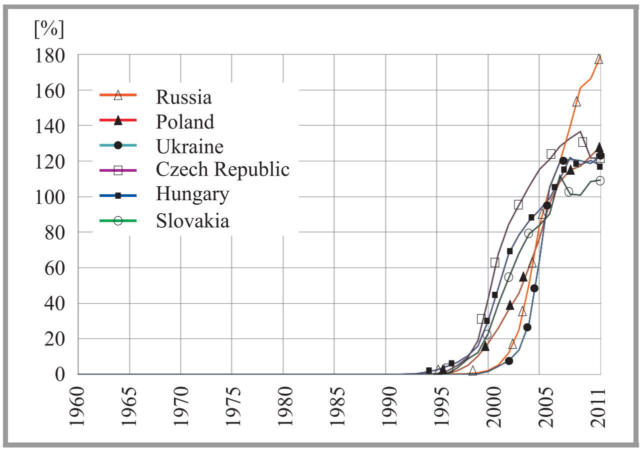

Fig. 5. Penetration of mobile services in selected countries of Central-Eastern Europe and Russia.

With regard to the development of mobile telecommunications, Africa is the weakest developed continent. Measured by penetration, the leading African countries are South Africa with penetration of 128% by the end of 2011, Morocco (112%), Egypt (102%) and Congo (95%). The weakest developed are Eritrea (5%), Ethiopia (17%), Burundi (15%), Djibouti (22%), Central African Republic (25%), and Chad (32%). The countries of the Middle East and Central East and Middle Asia have well developed mobile telecommunications.

As an addendum to the above short description of the world-wide development status of mobile telecommunications, the following analysis of Ericsson [4], Fig. 6 shows the breakdown of mobile penetration by the continents and certain selected regions as well as the global penetration ratio for November 2012. Surprisingly, the highest penetration was observed in Central Eastern Europe. It results from taking into account Russia, achieving an exceptionally high rate of 180% by the end of 2011, which may be due to a certain overreaction to the underdevelopment of fixed line telephony at the time before the transformation. The remaining positions in this chart are rather in-line with the general rating of the national economies of the countries located in the presented regions.

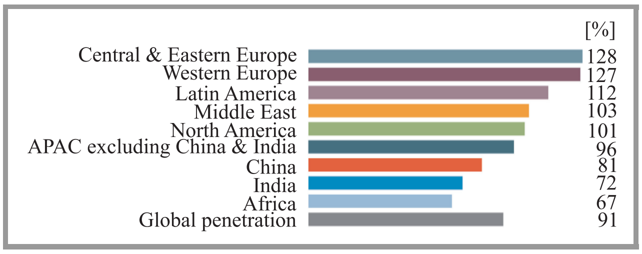

Fig. 6. Mobile penetration according to Ericsson Mobility Report, November 2012 in selected geographical regions (APAC – Asia Pacific).

The worldwide development success of mobile telecommunication takes root in more favorable economic characteristics for infrastructure development, as the cable-based access network is not necessary and the network construction time is much shorter than in the case of fixed line access networks.

However, the other reason of this success is the attractiveness and multitude of the services available through the mobile access networks, particularly in networks utilizing enhanced variants of GSM, such as HSPA and LTE.

4. Mobile Telecommunication Services

As mentioned, mobile communication systems were designed for personal telephone communications. For this reason, the first mobile terminals were simple radio-telephone sets. The term *mobile telephony* narrows down the meaning of this realm (though commonly used), because apart of voice services numerous services were developed based on data transmission and internet access.

Messaging services SMS and later MMS, gained great popularity, particularly SMS and afterwards emerged mobile payments, GPS service, a camera built in the handset, and others.

Still the highest significance has the use of mobile infrastructure for fast and ultrafast internet access, tied to spreading HSPA, HSPA+ and LTE technologies (and soon LTE Advanced). It can be claimed that the mobile infrastructure is becoming fast internet infrastructure, proved by the chart shown in Fig. 7 [4]. Apparently from 2009 the data transmission has prevailed over the voice transmission in the worldwide mobile traffic and this tendency becomes stronger as time goes by. The same source indicates that data transmission traffic may exceed 12 times by year 2018 [4].

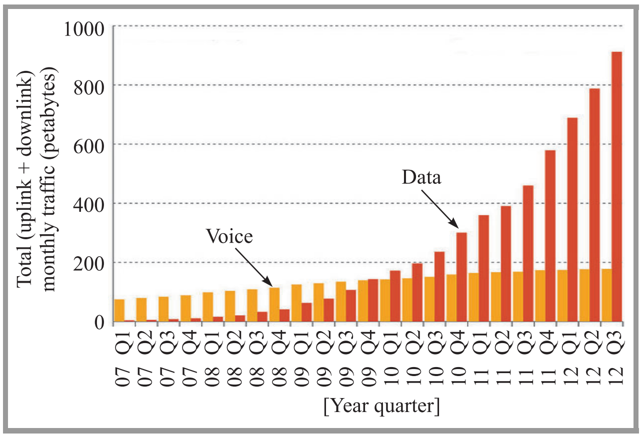

Fig. 7. Global telecommunication traffic in mobile networks.

With a high likelihood it can be assumed that the general trend for the ratio of voice traffic to data traffic is determined by the traffic in highest developed countries. In the developing countries, where the internet network is not yet sufficiently developed, most likely the voice traffic still prevails over the data traffic.

Analysis of the development of data transmission in internet networks, including mobile networks, conducted among others by Ericsson [4] and Cisco [5] indicate that the phenomenon of the high data traffic growth is primarily linked to the transmission of motion pictures (Internet TV, VOD, films download). They require high throughput networks and fast internet, attributable to countries with a rich telecommunication infrastructure. According to Cisco already today 5% of traffic is linked to this phenomenon, and expected to grow to 75% by 2016 [5].

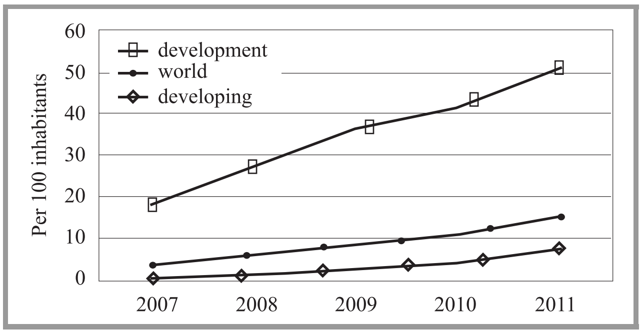

Fig. 8. Broadband mobile internet subscriber penetration worldwide.

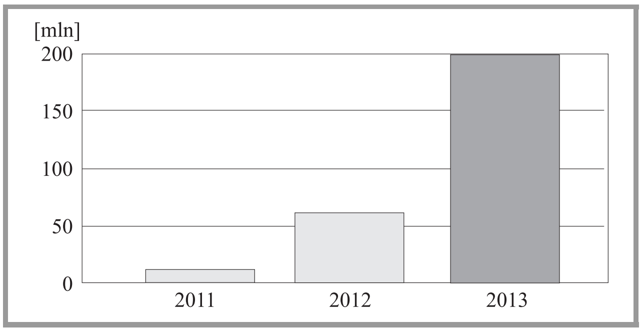

Fig. 9. LTE users worldwide.

Figures 8 and 9 presents both technical and functional development of mobile telecommunications tends towards taking over the role of the main internet transmission medium by the mobile infrastructure [6]. This phenomenon is unavoidable mainly due to lower costs for construction of access networks as well as technical (LTE development towards high data transfer rates).

5. New Terminals for Mobile Networks Step Up the Mobile Telecommunication Sector and Changes ICT Market

The progress in the development of mobile terminals has continued since the implementation of mobile telephony and it has substantially widened the scope of its services. During two decades the market have gone from bulky and heavy telephone sets resembling boxes (i.e., first terminals for NMT 450) to smartphones.

A smartphone with built-in internet access and other services is a small computer with a dedicated operating system (Android, iOS), built-in considerable memory and a large touch screen display replacing the numerical keypad. Some sets have built-in voice recognition, enabling voice-to-text conversion useful for, i.e., dictating SMS using voice. The present and future role of smartphones in daily life is worth reading in [7]. The essence is summarized by stating: "The smartphone of the future will be a constant companion, coach, collaborator, and advisor".

The growing popularity of smartphones caused by their versatility and rapidly increasing number of applications, affects other areas of activity. As a result of experiments conducted by Mayo Clinic in the USA the smartphone was recognized as a fully functional diagnostic device, enabling remote monitoring of the brain, heart activities, or the course of diabetes [8]. Recently the smartphone has been used as a proximity payment device in the NFC (Near Field

Communication) standard, which has a limiting impact on the payment cards market. Similarly, incorporating GPS into smartphones by end of the previous decade resulted in drop of demand and production of independent PND (Portable Navigation Device) [9]. Adding a digital camera to smartphones, initially with an average resolution, but then constantly improved and today comparable with popular compact cameras, has significantly limited the sales volumes of such cameras [10].

The number of smartphones in worldwide use as well as their impact on citizens' activity is growing quickly. According to forecasts by the Deloitte advisory reported in TMT Predictions in 2013 the number of sold smartphones should reach 1 bln, and by 2013 the number of smartphones in use should reach 2 bln [6] . [11] predicts that within next 10 years 5 bln people will have smartphones for both home and professional use.

In Poland the number of smartphones is growing rapidly as shown on Fig. 10 [5]. Probably the number of new mobile terminals was around 10 mln in 2012 and according to the forecast in Fig. 10 around 5 mln were smartphones. Because the total smartphone sales in previous years was around 5 mln sets, it can be estimated that 10 mln such sets operate in Polish mobile networks, i.e., around 25% of the number of active mobile terminals. It can be also presumed that within the next years, maybe by 2015, smartphones will dominate. That will have a fundamental impact on the spreading of internet service.

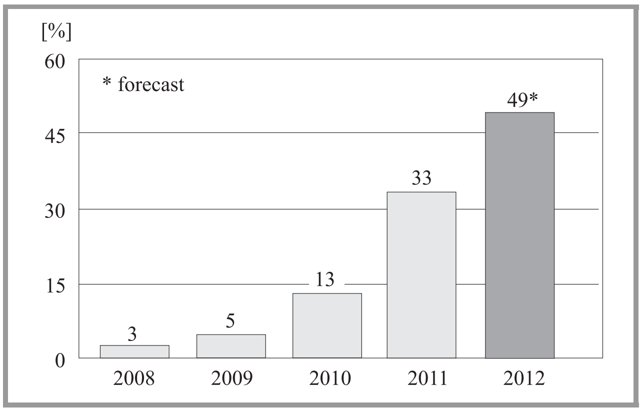

Fig. 10. Smartphones share in total number of mobile terminals.

In 2010 Apple released the first tablet called iPad, which initiated a rapid development of a new generation of personal computers tailored for mobile use. Apple's concept for such a tablet computer was soon found very useful and had many followers like Samsung, Nokia, LG, Microsoft, Google and others. The concept accurately met the needs of companies, whose employees frequently need instant access to company network resources from a remote location. Similarly to smartphones, a tablet has a touch screen display (with size 7–10 inch and HD resolution), most frequently an Google Android operating system and quite high computing power, comparable to middle range computer notebooks. This caused tablets to become a true success for both IT and mobile markets. The tablet became a mobile internet terminal successfully competing with the notebook, basically eliminating small computers called netbooks from the market, due to truly mobile properties like light weight, moderate size with a still significant screen size and a touch screen control.

According to tablet market data from North America during 2012 the notebook sales volumes achieved 64 mln while tablet sales 80 mln. But the global sales forecast for 2015 predicts sales of 276 mln tablets and 270 mln notebooks. During 2011 in Poland 120,000 tablets were sold, in 2012 possibly 0.5 mln [12]. The tablet spread forecast for the five biggest EU countries as a percentage of penetration is given in Table 1 [13]. Some other expert companies [14] forecast that within the next five years as many as 5 bln tablets will find their way to the global market.

Table 1
Tablet user penetration in selected EU countries, by percent of Internet users

Year	2010 [%]	2011 [%]	2012 [%]	2013 [%]	2014 [%]	2015 [%]	2016 [%]
UK	4	9	21	28	35	41	46
Italy	5	10	20	30	37	43	46
Spain	5	10	20	30	37	42	46
France	3	8	18	26	33	39	43
Germany	3	7	17	23	29	35	40
EU-5	3.8	8.5	19	26.8	33.6	39.5	43.8

According to Fig. 11 the large majority of smart connected devices are smartphones and tablets, together making around 70% of world market, which additionally proves their increasing share in the total number of mobile terminals [15].

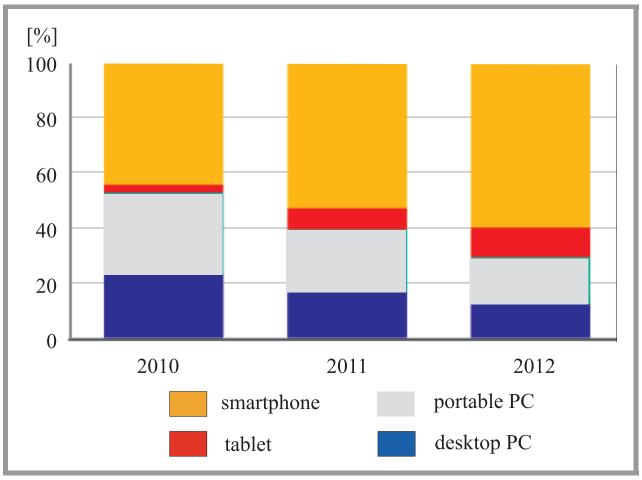

Fig. 11. Worldwide smart connected device market share by product category 2010–2012.

The borderline between a smartphone and a tablet is conventional, as the manufacturers of smartphones aim at increasing the smartphone screen size (i.e., Samsung with their high class sets Galaxy Note), and the manufacturers of tablets lower their costs by lowering tablet screen size, as in the case of Apple and their new series of size-reduced iPads, at a much lowered price [12].

As can be seen from the listed data, the significance of the emerging new smart terminals within the past five years cannot be underestimated, because it is an important catalyst for the increased importance of mobile telecommunications and mobile access to the internet.

It is highly probable that the great popularity of smartphones and tablets is still a privilege of the developed countries due to the still quite high prices of the devices. According to IDC [15] the average price of tablet becomes below 461 USD and of smartphone below 408 USD and the lowering trend continues. In Poland a high class smartphone Samsung Galaxy S3 LTE is available for around 2100 PLN, and the highest model of the Apple iPad for around 3500 PLN. As in the case of any popular mass product, prices of smartphones and tablets will undoubtedly drop significantly, hence the advantages of using them will be shared by a larger number of users, including those in developing countries. Thus far, the simpler models of mobile terminals, going out of use in the developed world, are still in common use in the developing countries.

6. Mobile Telecommunication in Poland

As previously mentioned, the mobile age began in Poland in 1992 by establishing the company Centertel, affiliated with the national telecom operator Telekomunikacja Polska, however, the true march to success began in 1996 by introducing GSM system with its later system enhancements. Poland was indeed successful in this realm as was already stressed and is proven on Figs. 4 and 5. The measure of this success is also the fact that the value of the mobile market is 60% of the value of the total telecommunication market and amounted to 23,432 bln PLN in 2011 (23,214 bln PLN in 2010).

According to GUS data [16] there were 23 mobile operators on the market in 2011, with the biggest ones Polkomtel, T-Mobile, Orange, Play, all four of them having their own countrywide network infrastructures. The fullest description of the mobile networks infrastructure and area coverage is given in the UKE report [17]. The report was created in accordance with the law [18] of 2010 voted in order to streamline investment processes in telecommunication networks, particularly for increasing the efficiency of utilizing financial means from EU aid programs. The law obliges both the concerned economic entities to report to UKE adequate information about the state of their infrastructure and UKE to publish such information in the respective annual report. The data for the report is prepared by UKE with the help of the National Institute of Telecommunication. The development issues of both mobile and fixed infrastructure, particularly in relation to the development of internet services are represented also in [19].

The analysis of data contained in reports [17] and [19] reveals that mobile service coverage is irregular and it is obvious that the privileged regions are: Central Poland, Lesser Poland, Silesia, Greater Poland and Gdańsk-Pomerania. The coverage maps of three major operators: T-Mobile, Orange and Play are similar, however, Polkomtel's map is unrepresentative due to the operator not supplying the pertinent data. In Fig. 12 sourced from [17] the coverage of map of Centertel (Orange) network is shown. Map of Poland is there colored by dots corresponding to localities within Orange network coverage. It seems that this network coverage is distributed evenly over the country's territory.

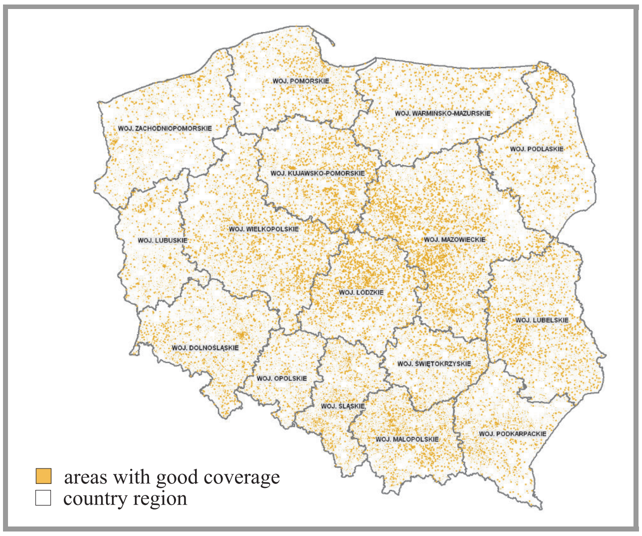

Fig. 12. Mobile operator Centertel (Orange) network coverage.

Considering mobile networks coverage and high penetration ratios (Figs. 4 and 5) one can claim that practically every citizen of Poland has access to mobile telecommunication services. During past two years important events occurred, which can have a significant impact on the mobile telecommunication infrastructure development. Mainly it concerns the LTE system and thus the internet services as well.

The first implementations of LTE in Poland appeared right after the world's first commercial installations of this system in the USA and Scandinavia. In October 2011 Polkomtel was purchased by holding of Mr. Solorz for an unprecedented amount 18.3 bln PLN, motivated mainly by the intention to build a powerful telecom-media company directed towards development of LTE and thus fast internet in Poland. According to information shared by Mrs Scheer of Polkomtel [20], LTE services are probably already being offered to around 20 mln citizens in Poland, in more than 3,300 localities, including 156 cities with more than 20,000 inhabitants.

In this way, Solorz's holding has created a real alternative competition for fixed line broadband internet service suppliers. In Poland, similarly to other countries utilizing radio access, the development of LTE mobile internet is naturally limited by the shortage of an available frequency spectrum. On February 13th, 2013 the result was published of the tender announced in 2012 for the reservation of frequencies in band 1800 MHz devoted to the development of LTE system and thus of the mobile internet infrastructure in Poland [21]. The winners of the competition were: operator Play with 3 blocks of 5 MHz each (total 15 MHz) and T-Mobile with 2 blocks (10 MHz). As a result of this tender the State Treasury received around a 950 mln PLN income. It indicates a high interest in the LTE development not only Solorz's holding, but also other operators.

Another tender (as an auction) is expected in 2013 for that part of band 800 MHz [22], which is the digital dividend linked with the digital switchover of the terrestrial TV in Poland and was occupied for the military applications until 2012. The spectrum of 2.6 GHz (and higher bands) may also be available, however, the band 800 MHz is mostly attractive due to a relatively lower network investment cost than in the case of higher frequencies. UKE president Mrs. Magdalena Gaj has estimated [22] that due to making this frequency spectrum [21] available to investors, LTE can encompass 90% of the country's territory, and the planned auction for band 800 MHz frequencies will allow to extend LTE services to less developed areas.

7. Conclusions

The progress in science and technology tied first of all to new abilities of reaching high speeds of digital data transmission during the past five years unexpectedly created a new alternative for the development of the broadband telecommunication infrastructure, which utilizes mobile systems.

Until recently, before LTE and LTEA were developed, fiber technology was regarded as perfect and useful for all known systems of electronic communications (FTTH technology – Fiber To The Home). It still remains such, as it is technologically perfect, stable and safe. Radio-based mobile systems have their natural limitations linked to the propagation of electromagnetic waves in free space, such as dependence on weather conditions, dependence of the effective bit rate on the distance from the base station as well as on subscriber-generated traffic and others. However LTE, and particularly LTEA, have numerous advantages in economy and functionality (mobility), and therefore in some circumstances they can compete with fixed line optical fiber access networks. It indicates the necessity of the realization analysis preceding the adoption of the right strategy for broadband infrastructure development.

In Poland the broadband telecommunication infrastructure has to be built practically everywhere, because it is a necessary condition of the social and economic development and it is an important goal of EU strategy known as Digital Agenda for Europe (DAE).

In Poland during past three years, many projects were undertaken with the support of EU funding aiming at the expansion of the broadband telecommunication infrastructure, mainly in the scope of building fixed line (cable) access and backbone (fiber) networks [19]. These projects create opportunities to substantially improve the status of the countrywide telecommunication infrastructure and realizing the goals of DAE. That was expressed by establishing 16 regional programs currently under execution as well as a large program for Eastern Poland, all of them related to building the broadband infrastructure.

Fortunately, besides these projects resulting from the initiative of the interested telecom operators, actions were undertaken aiming at the expansion of broadband mobile infrastructure, linked with wide-scale LTE implementations. The holding of Mr. Solorz companies has directed itself towards the development of LTE network and is already providing broadband LTE services. A new frequency spectrum was made available for building new LTE access networks. In 2013 an auction for the additional spectrum (800 MHz) will be conducted. Jointly it may lead to a substantial acceleration of the development of Polish broadband infrastructure and new opportunities for the entirety of mobile systems. It is estimated that as a result of these actions the chances to achieve the main DAE goal with respect to spreading fast internet access in Poland – ensuring every citizen an access speed of 30 Mbps by 2020 – becomes more realistic than it would appear from the state of our current assets, as was described in [19].

The strong trend for a successive replacement of mobile terminals by the new generation of smart connected devices able to achieve mobile access to many present and future services is a favorable outcome for the above plans.

New mobile terminals are changing not only the electronic communications but also the ICT market, due to first of all the important changes in the PC market, with respect to the growth of the demand for tablets and the downfall of the demand for personal computers, mainly desktops but also notebooks. The recently implemented new technology of so called *cloud computing* is contributing to these important changes of the ICT market.

In this connection taking into account all mentioned circumstances one can state that we are entering step by step into the new era anticipated and named by Steve Jobs (Apple Company) in 2007 as *post-PC computing*.

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Paper

Fading Duration in Line-of-sight Radio Links at 6 GHz

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Abstract—Broadband fixed wireless access, local multipoint distribution service networks are promising wireless solutions to connect fixed users to the backbone network instead of wired copper or fiber optic networks, via point-to-multipoint cellular networks. Channel capacity is of primary importance in broadband fixed wireless access networks due to increasing demand for multimedia services and possibility of providing wireless internet. Modern radio transmission systems are specifically designed for meeting two main objectives: to provide a solution for long distance networks with high transmission capacity, and to guarantee the highest link quality. Availability of a radio-relay system is very important and dependent on many factors, particularly propagation conditions in the troposphere. The article describes wave propagation that determines the performance of a radio-relay path at 6 GHz. Attenuation of received signal level measured in this frequency range depends on propagation condition on terrestrial path. Examples of measured fading duration of are presented.

Keywords—fading, line-of-sight radio links, multipath, propagation.

1. Introduction

The fast expansion of the applications and services in the wireless networks and the competition between operators have increased the demands for improving the performance work of these systems. The performance of broadband fixed wireless access links operating under 10 GHz is predominantly controlled by multipath attenuation. Time operation of radio links is split into two periods, when it is in working order or out of order. Radio links are out of order when even one of its basic parameters is crossing permissible limit spread. This occurrence is called failure. It is not essential the failure to follow rapidly or gradually.

There are six transmission parameters, which may be used to characterize unsatisfactory quality performance. These are BER (Bit Error Ratio) or FER (Frame Error Rate), short interruption, delay, jitter, slip and quantizing noise. BER/FER and short interruption are the main indicators of unavailability. This is because jitter and slip will cause bit errors and short interruption in the network and that delay and quantizing noise are relatively fixed quantities in any connection.

Line-of-sight radio relay systems are defined unavailable when one or both of the following conditions occur for more than 10 consecutive seconds:

- the digital signal is interrupted,
- the BER in each second is higher than 10^{-3}.

It should be noted that the unavailability for system has to be considered for both "the go" and "the return" direction, that is twice the calculated value. Wave propagation in the atmosphere and its impact on the performance of digital radio relay systems is the main topic of this paper.

2. Propagation – Mechanism of Fadings

The propagation of radio signals is affected by several factors that contribute to the degradation of its quality. One of more important factors leading to link unreliability is the environment, which leads to multi-path propagation effects and contributes to background noise. The radio refractive index of the atmosphere n, is a number on order of 1.0003, varying between 1.0 for free space – above atmospheric influence and about 1.00045 at the maximum. For greater computational convenience, it is customary to utilize a term N, called "radio refractivity", which is defined as:

$$N = (n-1)\cdot 10^6 . \tag{1}$$

The N term would be zero in free space, and a number on order at 300 at the earth surface. The radio refractivity of air is given as:

$$N = 77.6\frac{p}{T} - 5.6\frac{e}{T} + 3.75\cdot 10^5\frac{e}{T^2}, \tag{2}$$

where:

p – total atmospheric pressure [hPa],

T – absolute temperature [K],

e – partial pressure of water vapour [hPa].

The $5.6\frac{e}{T}$ element is very small compare to the other two and Eq. (1) can be given as:

$$N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right) = 77.6(N_s + 4810N_w), \tag{3}$$

where:

N_s – term is frequently referred to as "dry term" and

N_w – term is called as "wet term".

By examination of Eq. (3), it can readily be seen that, while pressure and relative index, temperature as a function of N is the predominating factor. It is easily seen why the phenomenon of temperature inversion is of concern in connection with radio propagation.

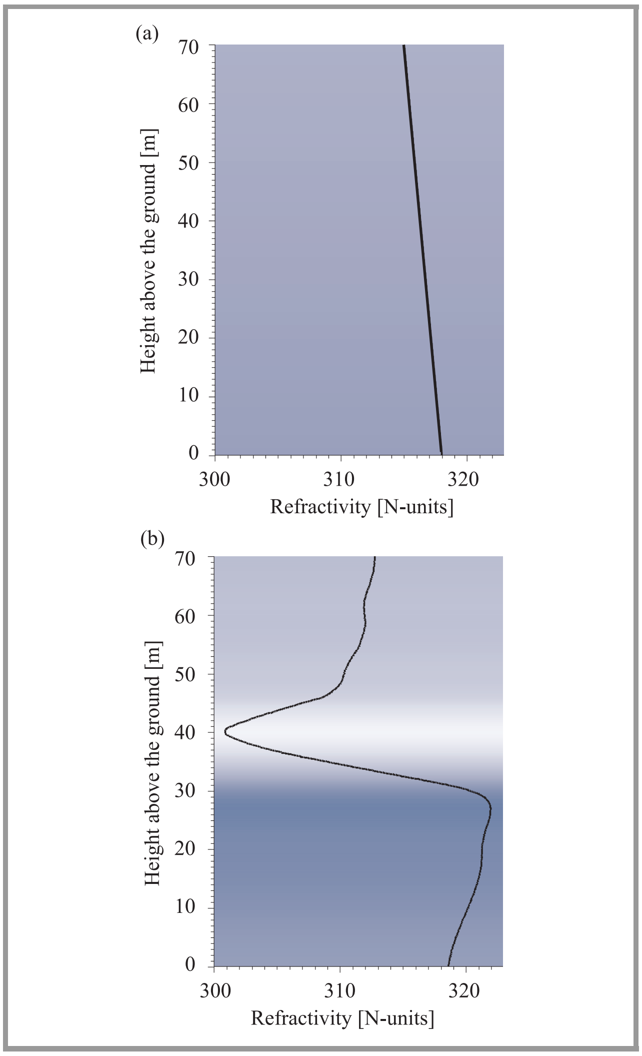

Fig. 1. The index of refraction for troposphere: (a) standard atmosphere, (b) atmosphere in elevated layers.

The beam of microwave energy is not a single line, but a wave front extending for considerable distance about center line. Since the index of refraction under normal atmosphere conditions is lower at the top of the wave front and higher at the bottom, and since velocity is inversely proportional to the index of refraction, the upper portion of the wave front under such conditions will travel slightly faster, with the result that the wave front as it moves along the path will tend to have the top tilted more and more forward. Since the direction of beam travel is always perpendicular to the wave front, the beam itself will be bent downward, thus increasing the apparent clearance. The amount of bending is actually very slight on a percentage basis, but is sufficient to cause significant variations.

Under certain atmospheric situations there can be even greater than normal negative N gradients (earth flattening type), or others in which the N gradients become less negative, or even positive. In the latter situation the lower part of the wave front will travel faster, and the beam will be bent upward, reducing the apparent clearance. This is earth-bulging type.

Most of the time gradients in the lower atmosphere are essentially linear (Fig. 1a). These linear variations affect clearance, and are also important when the path is reflective, but they do not produce atmosphere multipath situations.

When non-linear gradients occur such as shown in Fig. 1b, then there are suitable atmosphere conditions for multipath. These abnormal situations in the atmosphere can occur when conditions are such that stratified layers with different gradients may lie on top of one another. At night – before sunrise, radiation can cool the ground more rapidly then air, and the temperature may then increase with increasing altitude. Then it is possible to get the atmospheric multipath. Under these conditions the received signal is the vector sum of the various components, all of which are varying in phase in a random manner, and usually in amplitude as well. It is this phenomenon, which causes most of the fast, very deep fading.

3. Example of Empirical Data at Terrestrial Link 6 GHz

It is very important to estimate degradation of radio-relays. Meteorological conditions in the space separating the transmitter and receiver may sometimes cause detrimental effects to the received signal.

Six radio links of band 6 GHz were examined which paths were from 36.6 km to 69.8 km. Sites of 4 radio links were located near Warsaw and two of the longest paths were located at Mazurian Lakes District. Measurements were carried out during normal operation of radio links.

Signal samples were received with frequency 5 Hz during high attenuation and 0.0033 Hz in the other times. The empirical characteristics of signal attenuation were obtained from the four year measurements. The monthly attenuation due to multipath distributions and its duration time are presented in this paper. Number of fadings and their duration time in January of each measured year is presented in Fig. 2 and the same graph for August in Fig. 3.

The percentage of general number of fadings at 10 dB, 20 dB and 30 dB, which duration times were not longer than indicated on ordinate axis, in the fourth year measurement in January are presented in Fig. 4 and in August in Fig. 5.

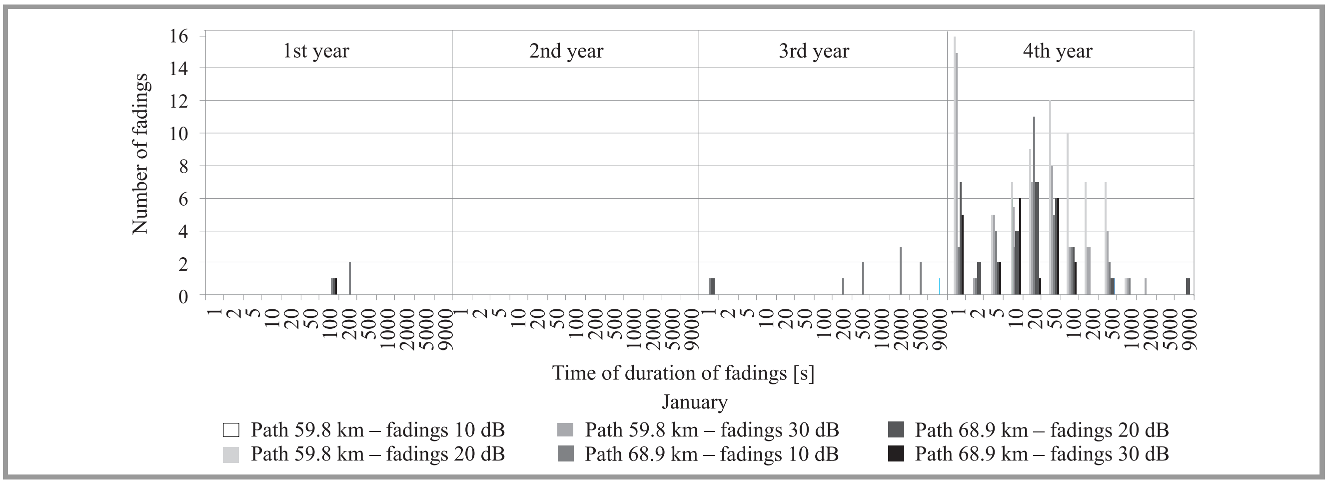

Fig. 2. Number of fadings and their duration time in January of each measured year.

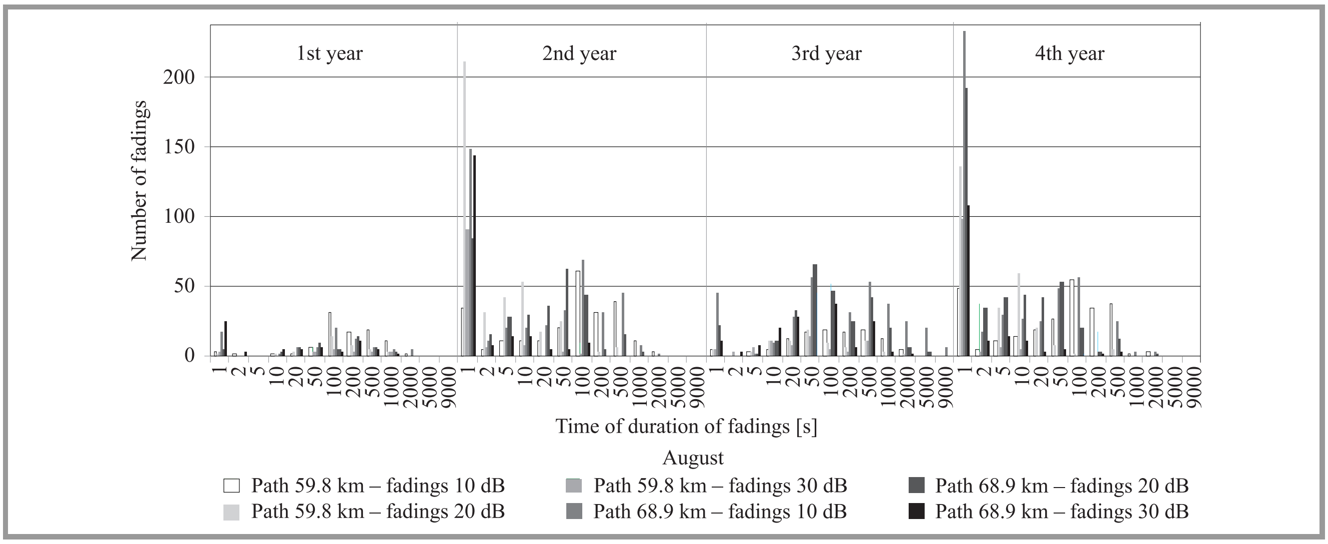

Fig. 3. Number of fadings and their duration time in August of each measured year.

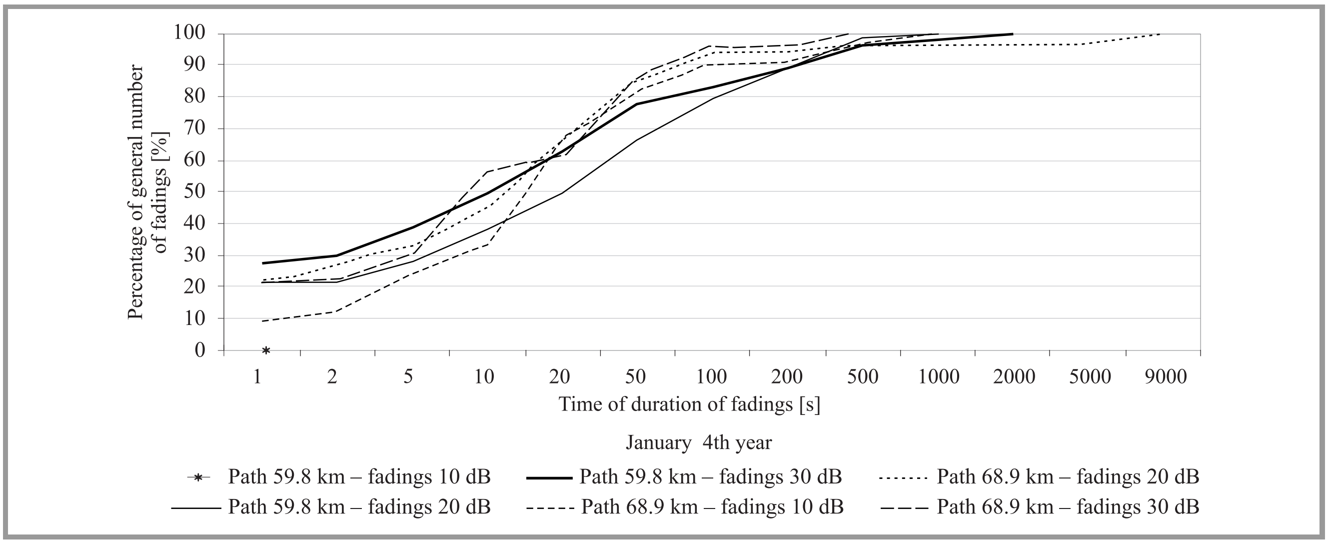

Fig. 4. Percentage of general number of fadings at 10 dB, 20 dB and 30 dB in January of the fourth year measurement, which duration times were not longer than indicated on ordinate axis.

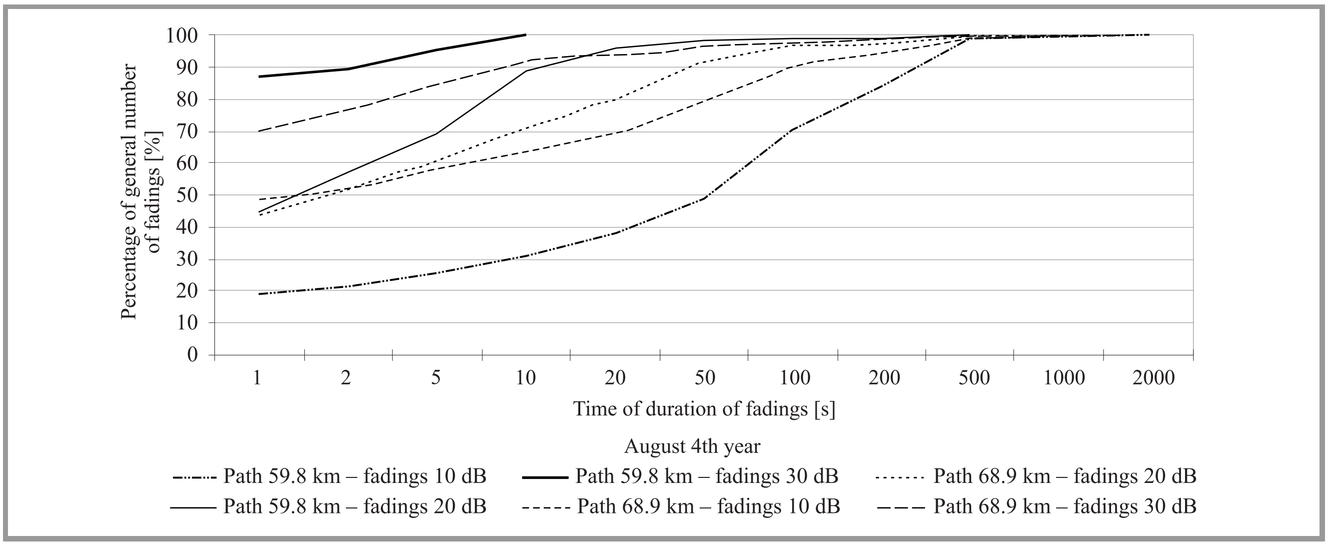

Fig. 5. Percentage of general number of fadings at 10 dB, 20 dB and 30 dB in August of the fourth year measurement, which duration times were not longer than indicated on ordinate axis.

4. Conclusion

This paper describes propagation effects in radiolinks applications. It has been experimentally validated in typical radiolinks of 6 GHz that when fadings approach near line-of-sight links are considered to free space value for typical atmosphere conditions.

Microwave radio links can be properly and precisely engineered to overcome potentially detrimental propagation effects. Knowledge of the fading statistics is extremely important for the design of wireless systems. During some stagnant, horizontally layered atmospheric conditions, the vertical gradient in atmospheric index of refraction produces multiple propagation paths between the transmitter and the receiver of line-of-sight microwave radio links. Microwave radio links can be properly and precisely engineered to overcome potentially detrimental propagations effects. The received signal varies with time, and the system performance is determined by the probability for the signal to drop below the radio threshold level or the receiver spectrum to be severely distorted. In order to estimate the performance of radio link system, it is very important to notice – what was found from measurements – that:

- attenuation of all events exceeding 30 dB resulted in situations when there were numerous short fadings,
- in case of lower levels, 10 dB, the exceedances lasted up to 5000 s,
- sometimes in winter months fadings did not occur.

Multipath fading in the atmosphere is not a permanent phenomenon. It occurs when there is no wind and the atmosphere is well stratified. It is more frequent at night and in the early morning hours and it is seldom felt at mid-day but never during periods of intense rain. In Poland it is frequent in July and August.

The effects of these materials have been investigated by means of real terms working radiolinks. This has permitted to integrate the influence of different materials on the tag performance into the models.

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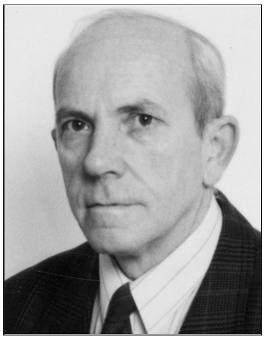

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Paper

Dual-band Multi Slot Patch Antenna for Wireless Applications

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Abstract—In this paper a novel configuration of broadband multi slot antenna for C/X bands is presented and analyzed. By cutting two diamond slots in the middle of the rectangular patch and three triangular slots in the right side of the patch, resonances can be created. Microstrip feed line is used in the down side region of the patch. Antenna characteristics were simulated using a finite element method (HFSS). According to simulations, the proposed multiple slot antennas can provide two separated impedance bandwidths of 970 MHz (about 11.96% centred at 8.11 GHz band) and 890 MHz (about 9.76% centred at 9.42 GHz band) and stable radiation patterns, promising for satellite systems.

Keywords*—*Ku/K band, microstrip patch antenna, multiband, satellite, slotted, triangular.

1. Introduction

Nowadays in radar and satellite communication applications, microstrip patch antennas are very popular due to their low profile, mechanically robust, relatively compact and light and possibility of dual frequency operation. They are easy and inexpensive to manufacture and can be conformable in planar and non-planar planes. Unfortunately they have some limitations, specially narrow bandwidth [1]. But presently, wider bandwidth is required for the increasing demand of modern wireless communication systems. Generally each antenna performs its function at a single frequency, so different antennas that are needed for different applications will cause a limited space problem. Researchers think that multiband antennas provide solutions to relief from this problem where single multiband antenna can operate at many frequencies for different applications. By applying fractal shape technique into antenna geometrics, multiband antenna can be constructed [2]–[6]. By using multilayer stacked patch [7] and single layer microstrip antenna [8] has been paid to little attention for achieving dual-band. In [9] dual frequency is achieved by cutting a square slot in the middle of a rectangular patch where they achieved both compactness and dual frequency operation. Dual frequency with tuneable frequency ratio can be attained by loading a pair of narrow slots parallel and close to the radiating edges of a bow tie patch [10]. Pre factual geometry and two short circuits in patch are used to achieve compact dual-band circular polarization antenna [11]. In [12], a rectangular shaped with complex slot cutting dual-band microstrip antenna for Ku band application have been proposed average gain is not good. Besides multilayer stacked patch, multi resonator, multi slot loaded antennas [13]–[17] are used for obtaining dual frequency but these structures have some disadvantages such as very complex, large, costly, thick substrate and difficult for manufacturing. On the other hand, using single feed antennas can diminish complication and high cost of the receiver front-end.

In this paper, a new broadband multi slot antenna with fractional bandwidth 11.96% and 9.76% is proposed. By arranging the geometry of the feeding structure in the below region, several resonant paths are created over the operating frequency bands. With a careful choice of the dimensions of the slots and shapes, these resonances can be merged together over the operating band and consequently the antenna can be used over a very wide bandwidth. Detail of the investigations based on simulations of the proposed antenna is described.

2. Antenna Design Architecture and Optimization

The proposed diamond and triangular slot antenna is shown in Fig. 1. The model was designed on Rogers RT/Duroid 5870 substrate with thickness 1.575 mm,

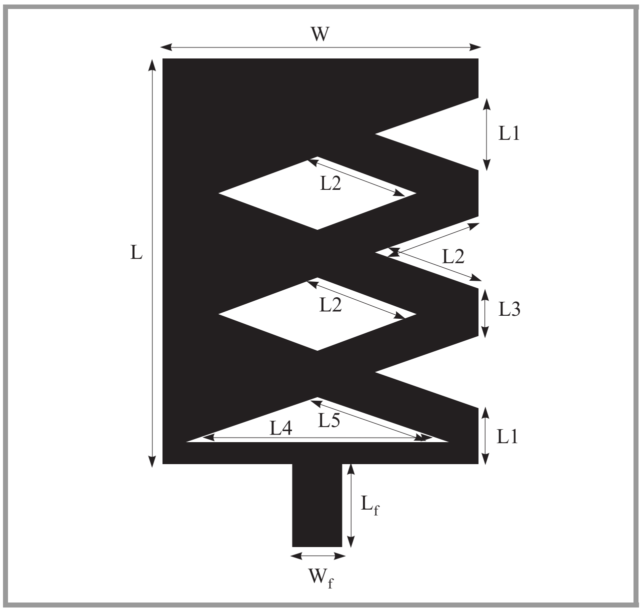

Fig. 1. Proposed antenna geometry layout.

$\varepsilon_r = 2.33$ and tan $\delta = 0.002$. The slot is etched on the patch. The length L of the slot is determined to be λg/in order to obtain a maximum power at the broadside direction. A microstrip-fed line on the bottom plane of the substrate is as a microstrip fed excitation of the slot antenna to excite the slot mode. Due to the higher impedance of the narrow slot, the width of the open circuited feed line is tuned and decreased more as before. The geometrical parameters of the multi slot antennas are presented in Table 1. During experiment, the dimensional parameters of the feed line were changed and compared in order to obverse the variation of the impedance bandwidth and the initial resonant frequency of the proposed slot antennas.

Table 1
Antenna dimensions

Parameter	Length [mm]
L	38
W	30
L1	6
L3	4
L5	11.73
L_F	10
W_F	4
L2	9.48
L4	22.71

3. Results and Discussions

The antennas were simulated using finite element based electromagnetic simulator HFSS (High-Frequency Structure Simulator). Figure 2 shows the simulated return loss against frequency for the proposed wideband dual frequency slotted antenna. It is clearly seen that simulated two resonant frequencies at 8.11 GHz and 9.42 GHz are excited with good impedance matching. The simulated lower resonant mode achieves a –10 dB impedance bandwidth of ranging from 7.84 GHz to 8.81 GHz with respect to the centre frequency at 8.11 GHz, and the upper resonant impedance bandwidth ranges from 9.18 GHz to 10.10 GHz with respect to the centre frequency at 9.42 GHz.

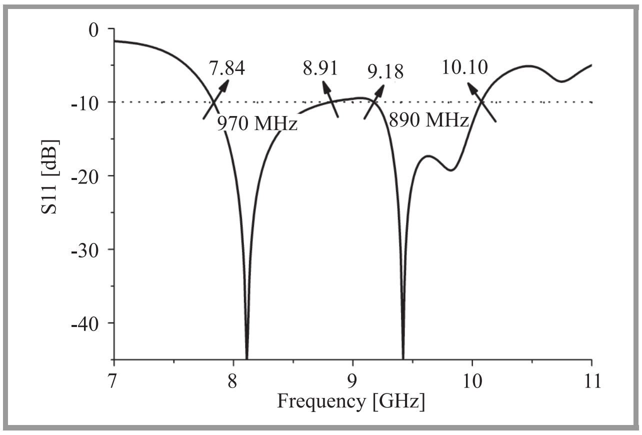

Fig. 2. Simulated return loss for the proposed dual-band antenna.

In order to achieve wide-band operation, the tuning parameters of the matching network have been studied. By adjusting the width of the 50 Ω microstrip line, we have a trade-off between impedance bandwidth and initial frequency as shown as following. Figure 3 show the smith chart and input impedance of the proposed shape antenna.

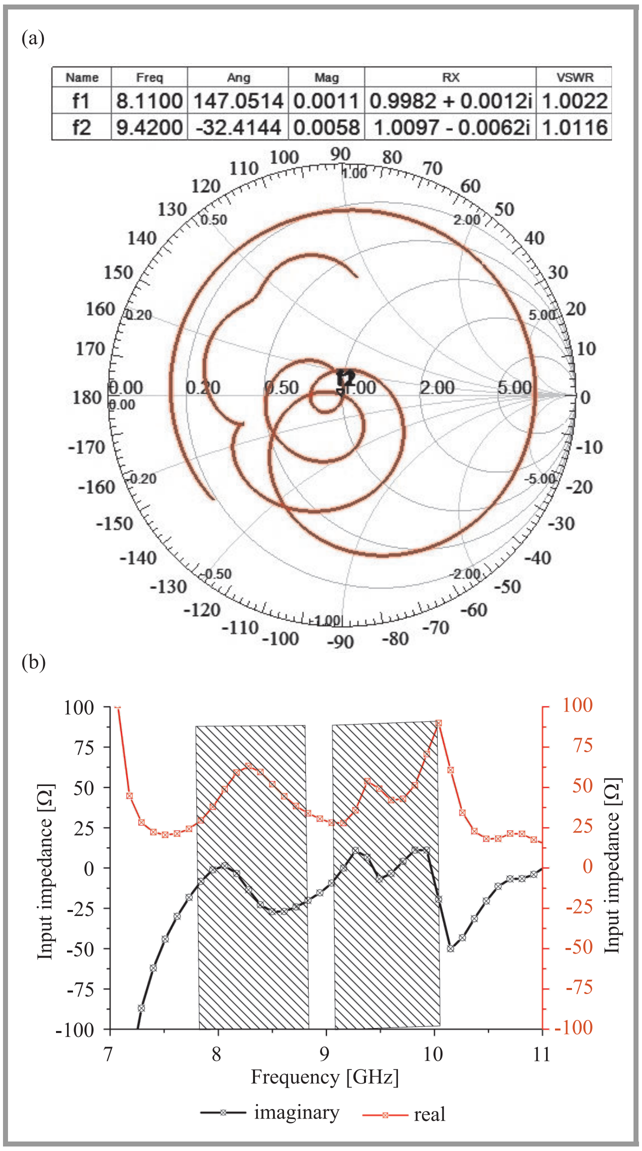

Fig. 3. Simulated (a) Smith chart and (b) input impedance for the proposed dual-band antenna.

The far-field radiation patterns for the proposed wideband dual frequency slotted antenna are also examined. Figure 4 shows the comparison between the simulated radiation

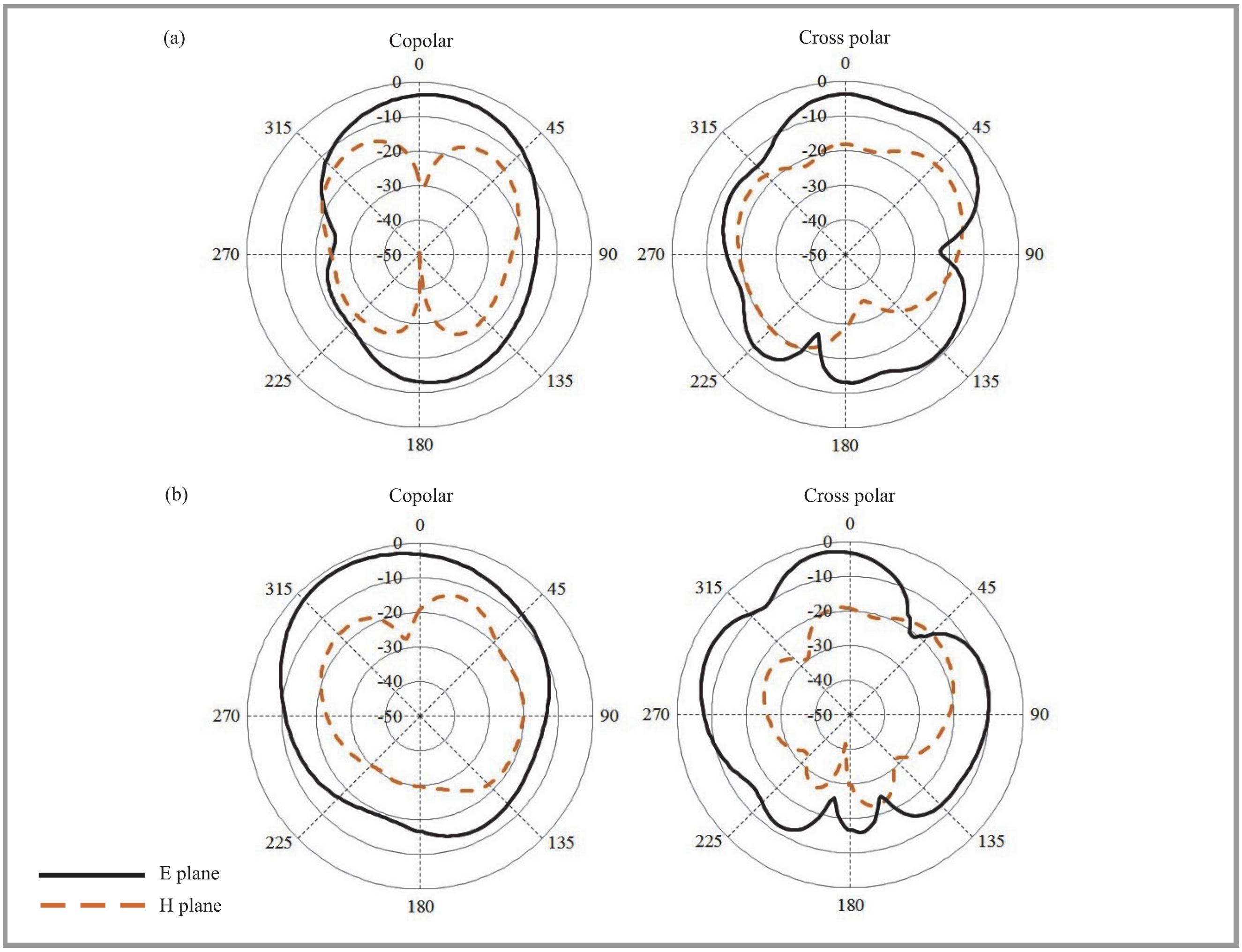

Fig. 4. E- and H-plane radiation patterns of the multi slot antenna at (a) 8.11 GHz, (b) 9.42 GHz.

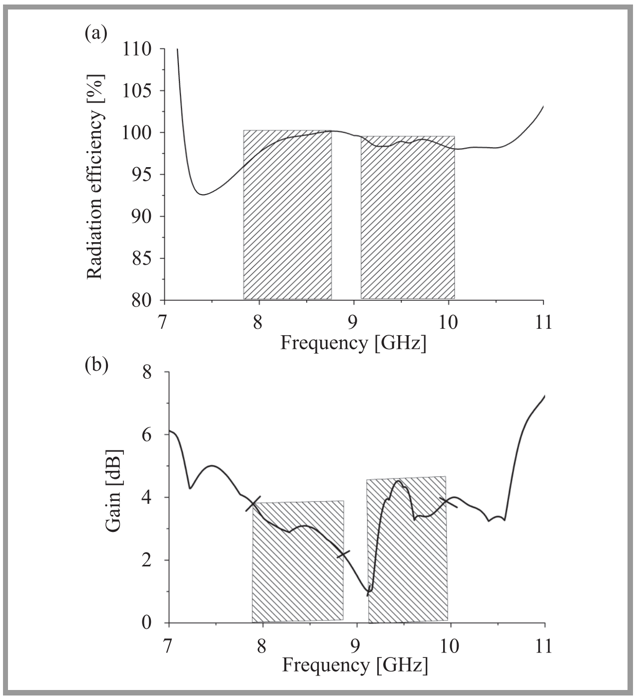

Fig. 5. Proposed antenna (a) radiation efficiency and (b) gain.

pattern including the horizontal (E plane) and vertical (H plane) polarization pattern for the antenna at lower band of 8.11 GHz and upper 9.42 GHz. Due to the much symmetry in structure of the proposed wideband dual frequency slotted antenna, rather all symmetrical radiation are seen in the horizontal and vertical planes as depicted in the plot. Typically, the radiation under the ground plane should be zero as same with the simulation radiation pattern. This is because the ground plane of the microstrip patch antenna serves as a reflector for all the radio frequency.

Figure 5 shows the radiation efficiency and gain of the proposed antenna. The average radiation efficiency and gain of the multi slots antenna are about 98.48%, 3 dB at lower band and 98.81%, 3.44 dB at higher band, respectively.

4. Conclusion

A novel design of wideband dual frequency slotted antenna which is constructed by two diamond shape slot in the middle and four triangular slot structures in the side of the patch is presented. The simulated result such as return loss, radiation pattern, and the gain of the proposed antenna is obtained and the overall performance of the antenna still can be considered in good condition. The proposed slotted dual-band antenna has a very simple structure, which makes the design simpler and fabrications easier, and is very suitable for applications in the access points of wireless communications.

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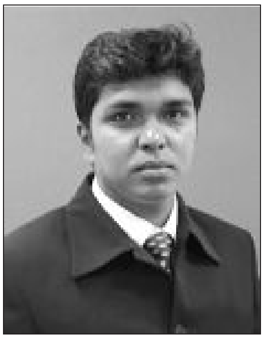

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Paper

High Q-factor Fabry-Perot Microresonator as an Alternative to Microdisk in Electro-Optical Modulator for Microwave-Photonic Receivers

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Abstract—In the last decade a new idea has been suggested for receivers of communication systems, namely, in microwave receivers' architecture. Though superheterodyne radio-frequency receivers are best suited to the needs of contemporary wireless communication, however stray radiation of their local oscillator (heterodyne) interferes with neighboring radio-devices and permits to locate the covert receiver. To overcome this drawback the signal transfer to optical range has been suggested. By this conversion, not only an elimination of receiver's stray radiation is attained but also vast advantages of photonic signal processing become available. The key element of existing microwave-photonic receivers is electro-optical microdisk modulator. However, its realization is complicated and as an alternative an electro-optical modulator based on high Q-factor Fabry-Perot microresonator is suggested. Comparative analysis of both types of modulators is performed, and advantages of high Q-factor Fabry-Perot microresonator based modulator are highlighted.

Keywords—electro-optical modulator, microwave-photonic receivers, wireless communication.

1. Introduction

In the last decade microwave (MW) communication systems expand rapidly the frequencies of their operation. While increase of operating frequencies is advantageous on the subject of communication speed, it revealed the serious problem related to the receivers' structure. The contemporary communication systems are exploiting superheterodyne radio-frequency (RF) receivers as they best satisfy the requirements of modern communication systems. These receivers have higher selectivity and sensitivity compared to the other types of receivers [1]. However, with the increase of operating frequency the stray radiation of heterodyne (local RF oscillator) is increased. This parasitic radiation becomes a source of interference for neighbouring radio devices. Moreover, what is undesirable, it is possible to locate the covert radio receiver and its operating frequency by means of this parasitic radiation. All this demands serious revision of MW receivers' construction.

There are several ways to reduce a stray radiation. One of them is the use of a stop-band filter on the way to antenna. The presence of this filter brings to the lessening of parasitic radiation, but does not eliminate it. Parasitic radiation may be reduced also at the expense of the schematic complication of the superheterodyne receiver [2]. While this method increases the size of the receiver and its power consumption, it cannot completely get rid of parasitic radiation. As the proper way out, the transition to the intermediate optical range has been suggested [3]–[7]. The essence of this approach is application of optical local oscillator (laser) instead of RF one. In this type of receivers, an incoming MW carrier loaded by low frequency signal, after passage through the RF input circuit is converted to the optical domain where advantages of optical signal processing can be exploited [8]–[10]. In the end, a photodetector retrieves the low-frequency signal. In this kind of a combined receiver, so called MW photonic receiver, besides getting rid of parasitic radiation in RF range, it is possible to attain the requiring sensitivity, selectivity and bandwidth, while having immunity to the external electromagnetic stray radiation, small size, weight and power consumption [3]–[7], [11]–[14]. The block-diagram of a MW photonic receiver is presented in Fig. 1.

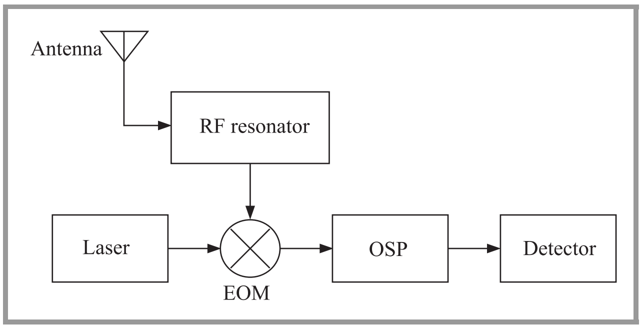

Fig. 1. Block diagram of microwave-photonic superheterodyne receiver: EOM – Electro-Optical Modulator, OSP – Optical Signal Processing.

To ensure high sensitivity and selectivity of this type of combined receivers it is necessary to have high Q-factor in the RF input part and high efficiency electro-optical transformation. While high Q-factor MW input circuitry is well established, the problem is finding a proper electro-optical modulator (EOM), which would ensure strong interaction between electrical and optical waves. This is possible only in optical resonant structure. The last permits to prolong electrical field interaction with optical wave confined within the resonator. From the known optical resonators for microwave-photonic receivers Fabry-Perot (F-P) and disk or ring one are the most suitable. The confinement of optical wave in F-P resonator depends on the reflectance of mirrors serving also for light input and output from the resonator. Higher is the mirrors' reflectance, stronger is the confinement of light within the resonator. The confinement is proportional to the light survive time within the resonator. In disk or ring resonators, an input/output of light from the resonator is performed through coupling via evanescent waves between disk and prism. These two types of resonators are described by the same mathematics and can be characterized with the same parameters, and their application depends on the feasibility [15]. An initial realization of MW photonic receiver is relied on EOM based on high Q-factor microdisk resonator [3]–[7], [11]–[14]. Recently the structure of EOM based on high Q-factor F-P microresonator has been suggested [16]. Below the brief description of both types of modulators is presented and advantages of F-P microresonator are discussed.

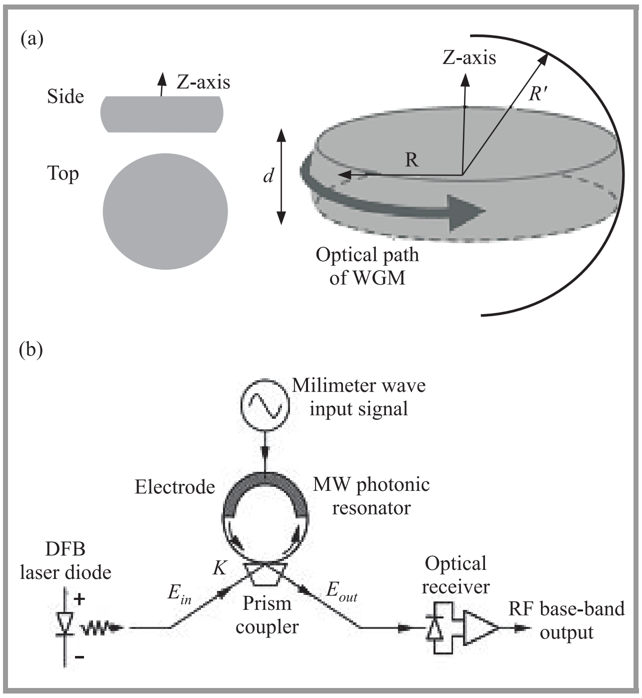

Fig. 2. Geometry of a microdisk: R – disk radius, d – disk thickness and curved side walls with radius of curvature R' (a); the receiver proposed for millimeter wave RF detection (b).

2. Electro-Optical Modulators of Microwave Photonic Receivers

2.1. Microdisk Electro-Optical Modulator

The first circular optical modulator for a microwave-photonic receiver was demonstrated in 2001 where a $LiNbO_3$ microdisk cavity has been used [3]–[5]. EOM uses a z-cut $LiNbO_3$ disk resonator with optically polished curved sidewalls (Fig. 2a). Evanescent prism-coupling is used to couple laser light into and out of a resonant TE-polarized high Q-factor optical whispering-gallery mode (WGM) which exists at the periphery of the disk. A metal electrode structure fed by an RF signal is designed to overlap with the optical field. The resonator's high optical Q-factor is used to increase the effective interaction length of photons with an applied RF microwave field. Combined with a simultaneously resonant microwave structure a highly sensitive receiver at microwave frequencies is achieved [3]–[7], [11]–[14]. Schematics of the receiver proposed for millimeter wave RF detection is presented in Fig. 2b [5].

An electromagnetic wave received by a RF antenna feeds electrodes of the microphotonic modulator. The modulator directly converts the RF signal to an optical carrier via the electro-optic effect. The phase- modulated optical signal is internally converted to amplitude modulation through interference with previous optical round trip.

The typical radius of $LiNbO_3$ microdisk is $R = 3.18$ mm and the thickness is $h \leq 1$ mm for operation at 7.67 GHz. The sidewall of the disk is optically polished with a radius of curvature R', which typically is equal to the radius of the disk. For operation as MW resonator, the gold electrodes are located on the top and bottom of the microdisk. RF signal from the microstrip line is applied to the metallic electrodes. For optical part operation, a single-mode laser injects optical WGMs inside the microdisk (at $\lambda_0 \approx 1550$ nm). The trapezoidal prism is used to input and output an optical radiation from the microdisk by means of evanescent waves. For this, the air gap between the microresonator and the prism should be about the optical wavelength to fit the optimal connection between the prism and the microdisk. The typical quality factor Q for the considered microdisk is $4.1 \cdot 10^6$, and the free space range (FSR) of optical spectrum is 7.67 GHz [3]–[5]. The resonant interaction of MW radiation with optical wave in the microresonator takes place when the microwave frequency is a multiple of the FSR of the microresonator. The frequency of the microwave carrier f_{MW} should be an integral multiple m of the optical FSR of resonator such that $\Delta f_{FSR} = \frac{1}{\tau_{disk}} = (2\pi Rn/c)^{-1}$ where τ_{disk} is the optical round-trip time of the disk, R is the radius of disk and n is the refraction index of $LiNbO_3$ in the corresponding optical range [3].

The semi-ring electrode is a standing-wave resonator with open ends so its resonant frequency can be easily tuned by changing its length. This property has made the semi-ring the preferred resonator in most microdisk modulator designs. The optical WGM is confined around the microdisk equator (due to the side-wall curvature) and the modulating electric field is confined between the electrode and the ground around the microdisk so the electro-optical overlap is relatively large. Due to the RF resonance in input electric circuitry the voltage across the microdisk larger than that of the input. The small thickness of the microdisk transforms the applied voltage to a large modulating electric field. Such modulators allow efficiently implementing microwave optical conversion and assuring required sensitivity and selectivity of contemporary microwave photonic receivers. However, challenges in fabrication of $LiNbO_3$ microdisks and demands in precision tuning of a microprism (serving for input and output of optical radiation into microdisk) hinder from their wide application. The last is confirmed also by the modest list of references in this area.

To get rid of above-mentioned complications it has been suggested to replace $LiNbO_3$ microdisk with a high Q-factor planar F-P microresonator based on $LiNbO_3$ operating element [16]. Planar configuration of a microresonator has advantages in realisation and the usage of a microprism stands no longer.

2.2. High Q-factor Fabry-Perot Resonator Based EO Modulator

It is known that F-P and microdisk resonators are identical with their optical characteristics and mathematical description, and therefore the choice of resonator's type depends on its feasibility [15]. These two types of microresonators (F-P and microdisk) differ by the round-trip. In the microdisk one the round-trip L_{RT} is equal to its circumference $L_{RT} = 2\pi R$, where R is the microdisk's radius. In the F-P microresonator $L_{RT} = 2L_{FP}$, where L_{FP} is the distance between the mirrors of the microresonator. The prototype of an EOM based on F-P microresonator is shown in Fig. 3 [16].

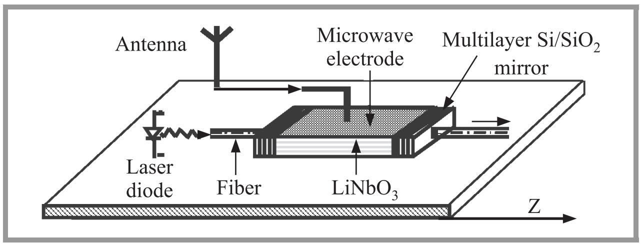

Fig. 3. Electro-optical modulator based on F-P microresonator with the multilayer mirrors.

The operating part of the microresonator based on the z-cut $LiNbO_3$ wafer. Multilayer mirrors at the transversal facets are alternating quarter-wavelength Si/SiO_2 layers implementing high Q-factor of optical microresonator. For input and output of light polished ends of fibers are tightly adjoined to multilayer mirrors. The top and bottom lateral facets are covered with layers of metal for microwave field supply.

Numerical simulation of optical characteristics of EOM based on F-P microresonator for application in MW photonic receivers is performed by the method of single expression [17]–[19]. The microresonant structure consisting of $LiNbO_3$ plate sandwiched between mirrors consisting of three pairs of quarter-wavelength layers of Si/SiO_2 allows attaining optical spectral characteristics identical with that of the microdisk optical microresonator [16]. The results of numerical simulations permit to assert that the proposed EOM based on F-P microresonator can be offered as an optically identical with microdisk resonator and can be considered as an alternative to the microdisk one.

Electro-optical characteristics of a modulator based on F-P microresonator are analysed by means of numerical simulation [20]. In the analysis an instantaneous change of the value of permittivity of $LiNbO_3$ plate under applied MW field is assumed. MW field is applied normally to the plate's plane.

At the optical resonance photons within the microresonator make a number of round-trips. When MW field is applied, any uncompensated change of the microresonator's local permittivity along the round-trip path of photons destroys the resonant state that is observed as an amplitude modulation in the output light.

Interaction of the MW field with the optical wave at the full coverage of the microwave top electrode along the F-P microresonator is considered. Interaction takes place due to second-order nonlinearity of $LiNbO_3$. It is known that the variation of the refractive index of $LiNbO_3$ crystal by the amplitude of applied electric field is expressed as: $\Delta n = n^3 \cdot r(33)E/2$, where $n = \sqrt{\varepsilon}$ is the refractive index at the absence of external electric field, $r(33)$ is an electro-optic coefficient of the material [4], [5]. According to the change of the sign of electric field (namely, to the change of its direction in space) the variation of the refractive index Δn changes the sign. As a result, an optical wave propagating in the microresonator meets the medium of changed permittivity, and as a consequence moves with varying phase velocity. By taking into account instantaneous change of the value of permittivity of $LiNbO_3$ plate under the applied sinusoidal MW field, the phase velocity of the optical wave V will depend on the value and frequency of MW field as follows:

$$V(t) = \frac{c}{\sqrt{\varepsilon + \alpha \cdot \sin(\omega t + \varphi)}}, \qquad (1)$$

where c is the speed of light in free-space, ε is the permittivity of $LiNbO_3$ plate at the absence of external MW field ($\varepsilon = 4.5$ at $\lambda_0 = 1550$ nm [4]), α is a coefficient of influence of MW field on the permittivity of $LiNbO_3$ plate (this value is determined by the product of electro-optic coefficient $r(33)$ and electric field amplitude of MW field), ω is the frequency of the MW field, φ is the phase of the MW field.

To obtain the frequency dependence of influence degree of sinusoidally changed MW field on the phase velocity of optical wave in F-P microresonator, it is sufficient to consider this process in the course of a round-trip in the microresonator. Efficient interaction of MW field with optical wave

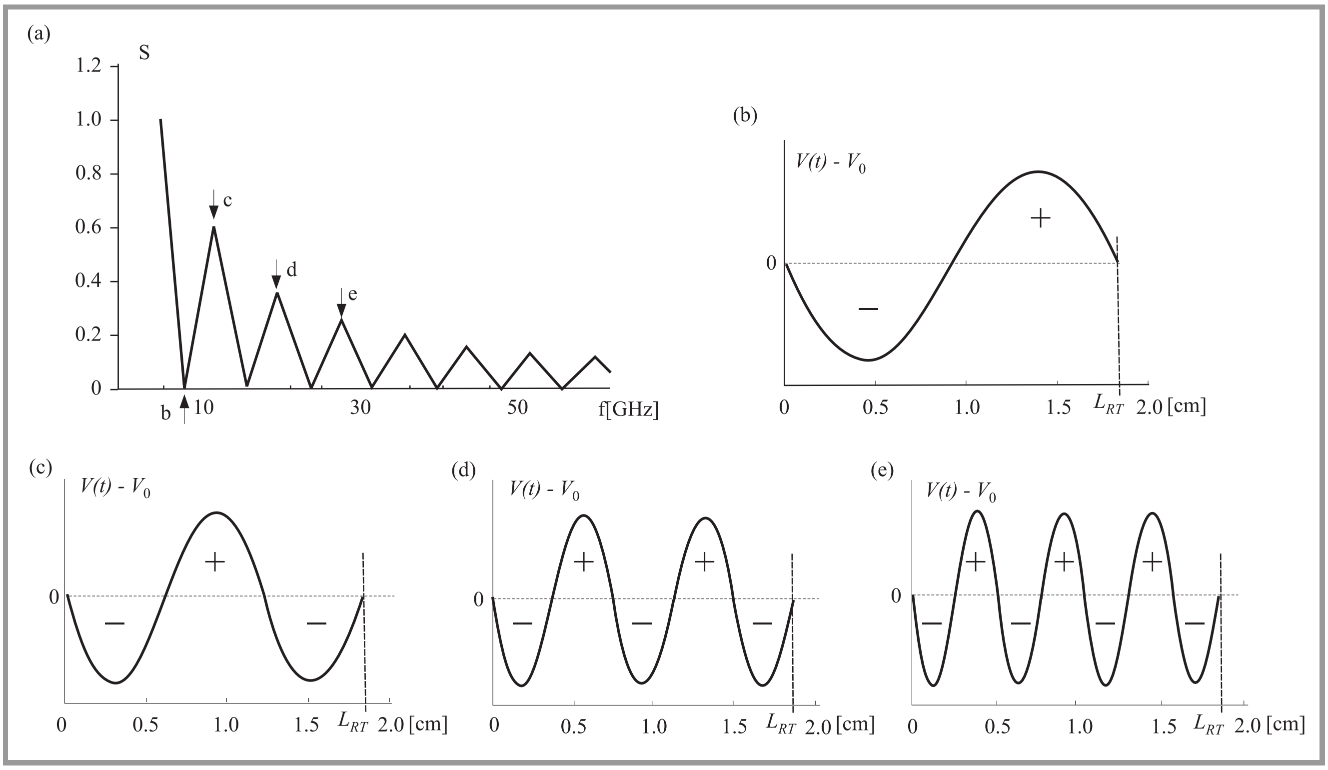

Fig. 4. The dependence of influence degree S on the frequency of applied MW field at the full coverage of the metallic electrode at $\varphi = 0^0$ (a); the distributions of optical wave velocity discrepancy along the microresonator at the point of the first zero interaction $f = \Delta f_{FSR} = 7.77$ GHz (b), at the points of maximal interactions: 11.65 GHz, 19.41 GHz and 27.18 GHz – correspondingly (c), (d), (e).

takes place during the round-trip of the optical wave when one or some wavelengths of MW field can be placed.

At the frequencies of MW field multiple to the fundamental frequency of the microresonator $f_m = \frac{1}{\tau_{RT}}$ full cancelation in variation of the speed of optical wave along the round-trip takes place. Here $t_{RT} = 2L_{FP}\frac{\sqrt{\varepsilon}}{c}$ is the time of a round-trip of optical wave in the microresonator at the absence of external MW field. As the fundamental frequency f_m is equal to the microresonator's free spectral range (FSR) $\Delta f_{FSR} = \frac{c}{2L_{FP}\sqrt{\varepsilon}}$, the periodicity of zero electro-optical interactions is equal to the integral number of Δf_{FSR}.

As the phase velocity of light is changed in accordance with Eq. (1), then it is reasonable to compute the value S that is the result of summation of positive and negative inputs of influence of MW field on the speed of light within the microresonator along the round-trip:

$$S = \left| \int_0^{2L_{FP}} \big(V(t) - V_0\big) \cdot dl \right|, \tag{2}$$

where $V_0 = \frac{c}{\sqrt{\varepsilon}}$.

It is reasonable to call this value S as an influence degree of MW field on optical wave in the microresonator. In Fig. 4a the dependence of the value of influence degree S on the frequency of MW field for the microresonator with the distance between mirrors $L_{FP} = 9.106$ mm and full coverage of the top metallic electrode is presented.

The first zero of waves' interaction takes place at $f =$ 7.77 GHz, which corresponds to the fundamental mode of the microresonator $f_m = \Delta f_{FSR}$. The peaks of maximal interactions have a strong periodicity according to the law $\frac{2m+1}{2} \cdot \Delta f_{FSR}$, where $m = 1, 2, 3\ldots$. With the increase of the frequency of MW field the influence degree S decreases, that is stipulated by decrease of non-compensated contribution of the change of the speed of optical wave during the round-trip (Fig. 4c–e). The obtained periodicities for the frequencies of zero and maximal interaction of waves are in an agreement with the corresponding data for microdisk resonator [3]–[7]. The effect of increase of operating frequencies of F-P electro-optical modulator with the decrease of the length of the top metallic electrode is also obtained [20]. The steps of frequencies are also in an agreement with the data for microdisk resonators [3]–[7].

3. Conclusion

The idea to transfer intermediate frequency of MW superheterodyne receiver in optical range is considering now as fruitful and prospective solution for different types of receivers [21]. By this operation it is not only possible completely to get rid of parasitic radiation in RF range, but also attain the high sensitivity, selectivity and bandwidth, while having immunity to the external electromagnetic stray radiation, small size, weight and power consumption [3]–[7], [11]–[14], [21].

Realization of this idea is relying strongly on construction of EOM providing effective interaction of MW electrical signals with optical wave. This key element of MW photonic receiver up to now is $LiNbO_3$ microdisk resonator, which not only needs precise microdisk preparation, but also optical wavelength scale positioning of microprism for light input/output from the microresonator.

An application of high Q-factor F-P microresonator instead of microdisk has been suggested recently [16], [20], that is prospective due to elimination of microprism from construction and application of planar structure instead of circular one.

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Paper

Evaluation of Potential Dangers of Mobile Telecommunication Frequencies and Modulations

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Abstract—Mobile Telecommunication is one of the fastest growing technologies in the world. The effects of its high frequencies and complex modulations to the exposed population are considered in this paper. Experimental studies examining a variety of effects on all levels of the organism, ranging from effects on single cells to effects which manifest themselves as reactions of the entire body, there have been a number of epidemiological studies in order to establish the possible causal correlations between higher exposures to HF EMFs. Recommendations on the reduction of the effects of EMFs of Mobile Telecommunication on humans was presented.

Keywords—electromagnetic fields, frequency, health, mobile communication, modulation.

1. Introduction

No technology covering virtually entire countries with its emissions has ever been rolled out as quickly as mobile telecommunications. This technology which comprises of either Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA) are electromagnetic fields (EMFs) based [1]. At the same time, there are only few direct studies of the potential health risks of typical mobile telecommunications frequencies and modulations for the exposed population. Also, many of the existing studies worked with high levels, which will only be found in rare cases in the real environment. High levels of high frequency electromagnetic fields can heat the absorbing tissue and trigger stress reactions in the body and thus with rising temperatures lead to thermal damage. Effects from high intensity high frequency EMFs, also known as thermal effects, on the central nervous system, the immune system, the cardiovascular system and the reproductive system including teratogenic effects, have been proven for mammals with a multitude of experiments [2]. The results of studies of the thermal effects of high frequency EMFs form the basis of the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which, in the past, were the basis for the guidelines set by the government in many countries. The base guideline was an upper limit on the Specific Absorption Rate (SAR), i.e., the amount of energy absorbed by the body from the field within a given unit of time.

According to ICNIRP, thermal damage will not occur at SAR values of below 4 W/kg and exposure levels of 0.4 W/kg for professional exposures and 0.08 W/kg for the general population are considered safe. Parallel to the experiments examining thermal effects, there have been a growing number of studies examining the effects on the body of HF EMFs at sub-thermal intensities. We now have a plethora of experimental studies examining a variety of effects on all levels of the organism, ranging from effects on single cells to effects, which manifest themselves as reactions of the entire body. In addition to the experimental studies, there have been a number of epidemiological studies in order to establish the possible causal correlations between higher exposures to HF EMFs, for example was found near base stations, and health damage amongst the population groups with higher exposures. The mobile telecommunications situation reflects, once again, the dilemma already known from chemical toxicology [3]. The study of potential health effects cannot generally compete with the speed of technical development and the roll out of the product. The extremely fast roll out of the mobile telecommunications technology and the accompanying public fear of the potential danger of this technology have stimulated research insofar that now we have more studies examining the effects of frequencies and modulations as used in mobile telecommunications on biological systems. There are also a growing number of experiments using lower intensities, reflecting the real conditions of exposure in the vicinity of base stations and equipment, so that effects found in the studies can be extrapolated into real life conditions.

The number of studies which examine the physiological effects of real mobile exposures is still very low, compared to the degree of penetration achieved by the technology and the number of (potentially) exposed persons. The World Health Organization (WHO) amongst others, have only recently begun to develop targeted strategies to examine the potential health risk from mobile telecommunications and results can earliest be expected within several years [4]. In the meantime, it is only possible to assess the potential dangers of mobile telecommunications using the results generated by uncoordinated research, which is still mainly orientated towards topics and criteria of relevant to science only, rather than addressing the requirements of society as a whole. Faced with a state of incomplete scientific research it is necessary to chose between two fundamentally different assessment theories when planning to assess the potential health risks of new technologies. Table 1 illustrates some typical artificial sources of electromagnetic fields with frequency and intensity. Natural sources like the magnetic field of the earth are not included. Note, however, that big variations occur.

Table 1
Typical sources of electromagnetic fields

Frequency range		Some examples of exposure sources
Static	0 Hz	VDU (video displays), MRI, diagnostic/scientific instrumentation, industrial electrolysis, welding devices
ELF	0 – 300 Hz	Powerlines, domestic distribution lines, home appliances, cars, train and tramway electric engines, welding devices
IF	300 Hz – 100 kHz	VDU, shops anti-theft systems, hands free access and control systems, card readers and metal detectors, MRI, welding devices
RF	100 kHz – 300 GHz	Mobile telephony, broadcasting and TV, microwave ovens, radar, portable and stationary radio transceivers, personal mobile radio, MRI

Section 2 examines the health risks to humans resulting from exposure to EMF of mobile telecommunications. Section 3 discusses about infertility and teratogenic effects and evaluation of results from experiments. Sections 4 and 5 conclude and recommend the precautionary measure needed in relation to exposures to EMFs of mobile telecommunications respectively.

2. Health Risks Resulting from Exposure to the EMFs of Mobile Telecommunications

The triggering of an illness caused by an (environmental) pollutant and the development of this illness are a multiphased process, which begins with a biological, biochemical or biophysical primary interaction of the pollutant with the biological system and ends with the manifestation of the illness. During the different phases of the process, the body's own repair mechanisms can intervene and impede the further development of the illness. An assessment of the potential health risks of electromagnetic fields as they are used for mobile telecommunications should therefore be mainly based on studies conducted directly on humans. Extrapolations from animal studies or even in vitro studies on cell cultures only have limited validity for effects in humans, due to the difference in susceptibilities and the lack of organic interactions in cell cultures [5]. However, due to the ethical limits to the research on humans, it is unavoidable to use results from experiments with animals, single organs or cells in order to discover the biological and physiological mechanisms.

2.1. Cancer

Given the results of the present epidemiological studies, it can be concluded that electromagnetic fields with frequencies in the mobile telecommunications range do play a role in the development of cancer. This is particularly notable for tumours of the central nervous system, for which there is only one epidemiological study so far, examining the actual use of mobile phones. The most striking result of this study was an obvious correlation between the side at which the phone was used and the side at which the tumour occurred. The brain tumour incidence however was only slightly increased. A hypothetical explanation of such a finding could for example be that mobile fields have a promoting effect on previously initiated (multiple) tumours, triggering a defence mechanism in the body which is capable of suppressing unpromoted tumours [6].

2.2. Higher Risks for Several Forms of Leukaemia

Although the studies in relation to testicular cancer were examining particular exposure conditions (emitting equipment worn partly on the body at hip level), given the high risk factor found, a possible risk cannot be excluded, especially not for mobile users wearing the devices in standby mode on their belts. The epidemiological findings for testicular cancer also need to be interpreted in conjunction with the results of the studies of fertility problems occurring in relation to high frequency electromagnetic fields. The risk factors for cancers other than testicular cancer are only moderately increased, but not negligible, considering this technology will potentially reach full coverage of the entire population [3].

Reliable conclusions about a possible dose-response-relationship cannot be made on the basis of the present results of epidemiological studies, but an increase of cancer risk cannot be excluded even at power flux densities as low as 0.1 W/m^2. In long-term animal experiments, the carcinogenic effect of pulse modulated high frequency fields was demonstrated for power flux densities of circa 3 W/m^2 (mouse, exposure duration 18 months, 30 minutes per day, SAR about 0.01 W/kg) [7]. On the cellular level, a multitude of studies found the type of damage from high frequency electromagnetic fields which is important for cancer initiation and cancer promotion.

Chromosome aberrations and micronuclei occurred at power flux densities from 5 W/m^2. Neoplastic cell transformation and an enhanced cell proliferation were demonstrated for SAR of below 0.5 W/kg, and individual studies demonstrated that the obvious disturbance of the com-

Table 2
Overview over the results of epidemiological studies with regards to the health risks of high frequency electromagnetic exposures

Illness	Number of studies (results)	Studies (results) with RR > 1	Statistically significant results
All illnesses	2	0	0
Cancer, unspecified	6 (7)	5 (6)	3
Brain tumours unspecified and tumours of the nervous system unspecified	14 (21)	10 (15)	6 (7)
Cancer (eyes)	1	1	1
Cancer of the respiratory organs, lung cancer	5	2	1
Chest cancer, men	2	2	0
Breast cancer, women cancer of the lymphatic and blood forming	3	3	2
System unspecified	4	4	1
Leukaemia unspecified	12 (16)	9 (13)	5 (7)
Acute leukaemia unspecified	4	4	0
Lymphatic leukaemia unspecified	4 (7)	2 (5)	1 (4)
Acute lymphatic leukaemia	2	2	0
Chronic lymphatic leukaemia	4	4	1
Leukaemia, non lymph. non-myelo	1 (4)	1 (4)	1 (2)
Lymphoma, Hodgkin-Syndrome	5 (7)	3 (4)	1
Testicular cancer	3 (5)	3 (5)	3 (4)
Uterine cancer	1	1	1
Skin cancer	4	3	1
Cardio-vascular diseases	4 (5)	3 (4)	1
Infertility, reduced fertility, men	4 (5)	3 (4)	1
Infertility, reduced fertility, women	1	1	0
Miscarriages, stillbirths, malformations and other birth defects	2 (3)	2 (3)	2
Cancer, offspring (parental exposure)	2	2	1
Neurodegenerative diseases, Alzheimer's	1	1	0
Disruptions of motor and psychological functions and well-being	2 (9)	2 (9)	1 (7)

munication between cells, which is a prerequisite for the uninhibited proliferation of cells that is characteristic for cancer development, occurs at just a few W/m^2 [3].

3. Infertility and Teratogenic Effects

Teratogenic effects of a pollutant can – as with the carcinogenic effect – either be caused by the triggering of a genetic defect or a harmful impact on the foetal development. The formation of a genetic malformation during its initiation phase is analogous to carcinogenesis, i.e., teratogenic effects are also caused by direct or indirect impact on the DNA and disruptions of the endogenous repair mechanisms [2]. Later damages of the foetus can either be caused by direct effects of the pollutant on the foetus or by reactions to the pollutant within the mother's organism, which would then be passed on to the foetus.

3.1. Evaluation of Results and Analysis from Experiments

However there are a much larger number of studies available, in which the health effects of high frequency electromagnetic fields in humans were examined (Table 2). Just under a quarter of all results relative to exposures with low frequency pulse or amplitude modulated high frequency fields, such as they are used for mobile telecommunications, even if the carrier and modulation frequencies are in most cases not identical with those of mobile telecommunications.

A statistical evaluation of the results is presented in Table 2. Here, we list for every illness how many studies or separate results are available, how many of these show a relative risk RR > 1 and how many are statistically significant. Almost all the studies, in which the total cancer risk without any differentiation according to tumour form were examined, showed a risk factor of RR > 1. Half of the studies resulted in statistically significant risk factors with a maximum value of 2.1, which corresponds to a doubling of the statistical risk to develop cancer from exposure to high frequency electromagnetic fields. A similar picture was found in relation to tumours of the nervous system, especially brain tumours. Here, the maximum value for relative risk found was 3.4.

Eleven of the total of 15 studies yielded a positive result, more than half of which were statistically significant. The incidence of breast cancer in relation to high frequency fields must be examined separately for men and women. All three studies relating to the breast cancer incidence in women yielded risk factors greater than 1, the statistically significant values were 1.15 and 1.5. For men, risk factors of up to 2.9 were found, however, not all were statistically significant. Of the total of 16 results for leukaemia without further differentiation of the illness, 13 were positive (RR > 1), more than half of these results were statistically significant.

The highest statistically significant value for the relative risk was 2.85. Amongst the results of the differentiated studies, the following are notable: lymphatic leukaemia (7 results, 5 positive, 4 statistically significant, RR maximum value 2.74) and acute myeloic leukaemia (4 different studies, 3 positive results, 2 statistically significant, maximum RR value 2.89).

With regards to the correlation of high frequency electromagnetic fields from radar and other sources and testicular cancer, three studies have been conducted. All lead to statistically significant risk factors with a maximum value of 6.9. The studies regarding cardio-vascular diseases did not result in a clear picture, not least because of the multitude of the symptoms examined. All four studies of fertility problems in relation to the exposure of men to microwaves indicate increased risk. In two studies statistically significant risk factors of up to 2.7 were found. With regards to irregular courses of pregnancies and malformations in children of mothers which had been exposed to high frequency fields, there are a large number of studies with positive results, of which only two fit into the frequency range relevant to our report. Both of these studies found statistically significant positive results with risk factors of up to 2.36. Of the studies of cancer risk of children whose fathers had been exposed to electromagnetic fields, only two correspond to the quality criteria required for inclusion into this report. Both indicate an increased risk, but only one result is statistically significant at a value of RR = 2.3, with regards to the cancer risk of children in correlation to the exposure of their parents [5].

Regarding the disruption of motor functions as well as psychological functions and wellbeing, there is only one valid study for the frequency bands relevant to this report, which yielded a slightly increased risk factor. However since other studies of transmitters with frequencies below 100 MHz resulted in serious indications of increased risk, indicating that this problem should be given more attention in the future, we also included the study of [8], although it didn't meet our quality standards with regards to the statistical evaluation. Unfortunately, the majority of the studies do not state the actual strength of the exposures. Measurements are only available for the radio and television transmitter used for the studies of [9] and [10]. The mean power flux densities for all 16 municipalities affected by this transmitter were 3.3 W/m^2 within the range from $2.6 \cdot 10^{-4}$ to $1.46 \cdot 10^{-2}$ W/m^2 [9].

4. Conclusion

An assessment of the potential health risks of electromagnetic fields as they are used for mobile telecommunications should therefore be mainly based on studies conducted directly on humans. Extrapolations from animal studies or even in vitro studies on cell cultures only have limited validity for effects in humans, due to the difference in susceptibilities and the lack of organic interactions in cell cultures. The analysis of the results of the studies for all stages shows the effect of EMFs on humans, however this can be prevented or reduced.

5. Recommendations

5.1. Precautionary Health Protection in Relation to Exposures to Electromagnetic Fields of Mobile Telecommunications

With mobile telecommunications we have to differentiate two exposure situations:

- exposure of residents near base stations,
- exposure of mobile users when using the devices.

To limit exposure to an acceptable degree, if this is possible at all, there is need for different strategies for the two different exposure groups.

5.2. Exposures from Base Stations

In humans, harmful organic effects of high frequency electromagnetic fields as used by mobile telecommunications have been demonstrated for power flux densities from 0.2 W/m^2. Already at values of 0.1 W/m^2 such effects cannot be excluded. If a security factor of 10 is applied to this value, as it is applied by ICNIRP and appears appropriate given the current knowledge, the precautionary limit should be 0.01 W/m^2. This should be rigorously adhered to by all base stations near sensitive places such as residential areas, schools, nurseries, playgrounds, hospitals, churches, Mosques and all other places at which humans are present for longer than 4 hours. We recommend the precautionary limit of 0.01 W/m^2 independent of the carrier frequency. The rough dependency on frequency with higher limits outside of the resonance range, as it is applied in the concept of SAR, is not justifiable given the results of the scientific studies which conclusively prove non-thermal effects of high frequency fields.

5.3. Exposures of Mobile Phone Users

Given the state of technology now and in the near future, it is currently technically impossible to apply the recommended maximum value for mobile base stations also to the use of mobile phones. However, a lowering of the guidelines to a maximum of 0.5 W/m^2 should urgently be considered. A particular problem in this exposure group is posed by children and adolescents, not only because their organism is still developing and therefore particularly susceptible, but also because many adolescents have come to be the most regular users of mobile phones. Furthermore, particular efforts should be made to lower the exposures during calls. It would be recommendable to conduct (covert) advertising campaigns propagating the use of headsets. It would also be important to develop communications and advertising aiming at minimizing the exposures created by carrying mobile phones in standby mode on the body.

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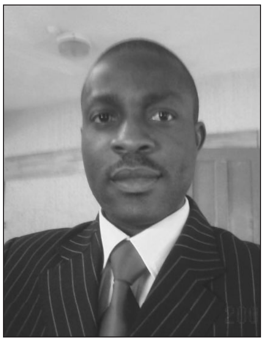

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Paper

Enhancement of Speech Communication Technology Performance Using Adaptive-Control Factor Based Spectral Subtraction Method

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Abstract—This paper presents speech enhancement technique based on Spectral Subtraction (SS) method. SS is a renowned noise reduction technique that works on the principle that noise spectrum estimate over the entire speech spectrum can be subtracted from the noisy signal. On the contrary, most of the noise encountered in the real-world conditions is majorly colored. Unlike Additive White Gaussian Noise (AWGN), colored noise does not affect the speech signal uniformly over the entire spectrum. To mitigate effects of colored noise on the processed signal, we propose a Multi-Band Spectral Subtraction (MBSS) method using novel Adaptive-Control Factor (ACF). The spectrum is divided into frequency sub bands based on a nonlinear multi-band frame and various signal-to-noise ratios (SNRs) are considered. The proposed scheme results in better system performance with quality signal and unlike the basic SS method. It mitigates the effects of anomaly known as "musical" tones artifacts in the processed signal that result in residual noise and speech distortion. The computational complexity involved is minimal. Furthermore, simulation results show that the proposed algorithm removes more colored noise without removing the relatively low amplitude speech signal over the entire speech spectrum. Subjective listening tests, with clean speech signals and different noise levels, show discernable performance of our proposed method when compared with the conventional SS approach.

Keywords—Adaptive-Control Factor, MBSS, musical noise, subbands.

1. Introduction

Advances in digital signal processing have improved the quality of the existing and emerging communication technology services such as mobile telephony, teleconference systems, and Voice over Internet Protocol (VoIP). The corruption of speech signals due to presence of additive background and channel noise causes severe difficulties in various communication environments. Noise presence frequently degrades the quality of services and the information content of a signal [1]. To improve the quality of the corrupted signals, noise must be eliminated or suppressed. Noise suppression techniques are essential for these systems to operate efficiently [2].

In [3] Boll proposed Spectral Subtraction method of suppressing the effect of noise acoustically added to the speech signals. The approach is popular because of its simplicity and versatility in concept and effectiveness in enhancing speech degraded by additive noise [4]. The basic principle of the spectral subtraction method is to subtract the magnitude spectrum of noise from that of the noisy speech. The approach works under the assumption that noise signal is uncorrelated and additive to the speech signal [2]. While this power spectral subtraction method substantially reduces the noise levels in the noisy speech, it can cause deterioration of the recognition accuracy as well as introduce further distortion – called musical noise – in the speech signal [5], [6]. Musical noise consists of tonal remnant noise components that are annoyingly unpleasant to the ear.

Recent studies have focused on a nonlinear method to the subtraction process – justified by the variation of SNR across the enhanced speech spectrum [2], [7]. The spectrum of colored noise is not flat like the assumed white Gaussian noise. Consequently, the noise signal does not affect the speech signal uniformly over the whole spectrum. Certain frequencies are affected more adversely than others.

To prevent the variation of SNR across the enhanced speech spectrum and destructive subtraction of the speech while removing most of the residual noise, it is necessary to develop an appropriate factor that will subtract only the necessary amount of the noise spectrum from each frequency bin. In [8] criterion to quantify the amount of generated musical noise was proposed.

In this paper, a multi-band approach to spectral subtraction method that maintains a high speech quality and mitigates the stated anomalies using new Adaptive-Control Factor (ACF) is proposed. The ACF allows for the removal of less noise during relatively low amplitude speech and more noise during relatively high amplitude speech. The proposed approach divides the spectrum into frequency subbands based on a nonlinear multiband frame. For each sub-band, the noise corrupted speech spectrum in preceding and current time frames is compared to statistics of the

noise spectrum to improve the determination of the speech activity in a given sub-band.
The mathematical descriptions of the MBSS and the proposed ACF are discussed in Section 2. Section 3 discusses the implementation of MBSS with ACF. Section 4 contains experimental results of the research. Conclusions are drawn in Section 5.

2. Multi-Band Spectral Subtraction

Suppose a clean signal $s(n)$ is corrupted by a stationary additive noise $d(n)$. The resulting received corrupted signal can be expressed as

$$r(n) = s(n) + d(n), \tag{1}$$

where n is the discrete time index. The power spectrum of the received signal, at k instant, can be approximately estimated from:

$$|R(k)|^2 \approx |S(k)|^2 + |D(k)|^2. \tag{2}$$

The received signal is buffered and divided into segments of N samples length. Each segment is windowed, using Hamming window technique, and discretely Fourier transformed to N spectral samples. Windowing alleviates the effects of discontinuities at the endpoints of each segment and suppresses glitches. Therefore, it avoids the broadening of the frequency spectrum caused by the glitches [7], [9].

Following [3], the clean speech spectrum estimate is obtained as:

$$|\hat{S}(k)|^2 = |\hat{R}|^2 - \alpha|\hat{D}(k)|^2, \tag{3}$$

where α denotes an over-subtraction factor. This factor is for controlling the amount of noise subtracted from the noisy signal. For full noise subtraction, $\alpha = 1$ and for over-subtraction $\alpha > 1$.
A novel Adaptive-Control Factor $\alpha(k)$ is proposed that allows controlling mechanism within each frequency-band k, giving that noise is colored and has non-uniform spectral distribution. This ACF is scaled to accommodate for the multiple-frequency range that may exist in speech spectrum, expressed as:

$$\alpha(k) = \begin{cases} \left|\dfrac{f}{2\beta(k)}\right| & f \leq 2 \text{ kHz} \\ 1 & f > 2 \text{ kHz} \end{cases}, \tag{4}$$

where $\beta(k)$ is the normalized value of the noise spectrum dictated by the level of the signal. The $2\beta(k)$ accommodates for peak-to-peak consideration, and the frequency f is in kHz. The floor-noise may have approximate frequency as that of power-line interference and its harmonic component at about 50 Hz. The inclusion of frequency-components of $f < 50$ Hz is to accommodate the situation when the speech is contaminated by disturbances close to the signal being generated such as extragenoeous low-frequency, high-bandwidth components caused by body movement, and/or nearby processing equipment. Further, the border of $f \leq 2$ kHz reflects the limit where extraneous noise becomes problematic for normal speech recording range.

3. Implementation

The signal is first windowed using a 20 ms (160 samples) window and 50% overlap between frames. The magnitude spectrum of the windowed signal is estimated using 256 points Fast Fourier Transform (FFT) at 8 kHz sampling frequency. The noisy signal spectrum is divided into K sub-bands, and average value of the segmental SNR is calculated over each preceding and succeeding k-th sub-band. Then, spectral subtraction was implemented independently across multiple sub-bands by subtracting the estimated noise magnitude spectrum in each k-th sub-band from the noisy signal spectrum using ACF. This prevents both over and under subtraction as well as signal distortion. The estimated noise magnitude spectrum in each k-th sub-band is subtracted from the noisy signal spectrum. The processed k-th sub-bands are combined and then the enhanced estimate of the signal is obtained by the Inverse Fast Fourier Transform (IFFT) of the enhanced spectrum using the phase of the original noisy spectrum. The resulting signal is overlap added to reconstitute the output enhanced signal sequence. Different noise scenarios were considered with variable intensity and sub-band variable frequencies to test the effectiveness of MBSS technique.

4. Experimental Results

4.1. Simulation Results

Firstly, a real-world low-level noise scenario environment like home or office is considered. In this situation, $4.5 \cdot 10^4$ samples of real-world noise are added to the same value of clean speech signal, as shown in Figs. 1a-c the composite noisy signal. The implementation of the proposed MBSS gives satisfactory enhanced speech, as seen in Fig. 1d.
Furthermore, a real-world medium level noise scenario like campus environment is considered. In this condition, $4.5 \cdot 10^4$ samples of medium level noise are added to the same value of clean speech signal, as shown in Figs. 2a-c the composite noisy signal. Fig. 2d depicts enhanced speech obtained with the implementation of MBSS.
Additionally, this paper further examined a high-level noise environment to experiment effectiveness of the proposed approach. A real-world high-level noise scenario like manufacturing company is analyzed. In this environment, noise emanates from different sources like heavy duty generator and production machines. In this situation, $4.5 \cdot 10^4$ samples of real-world noise are added to the same value of clean speech signal, as shown in Figs. 3a-c the composite noisy signal. The implementation of MBSS gives satisfactory enhanced speech, as seen in Fig. 3d. In addition,

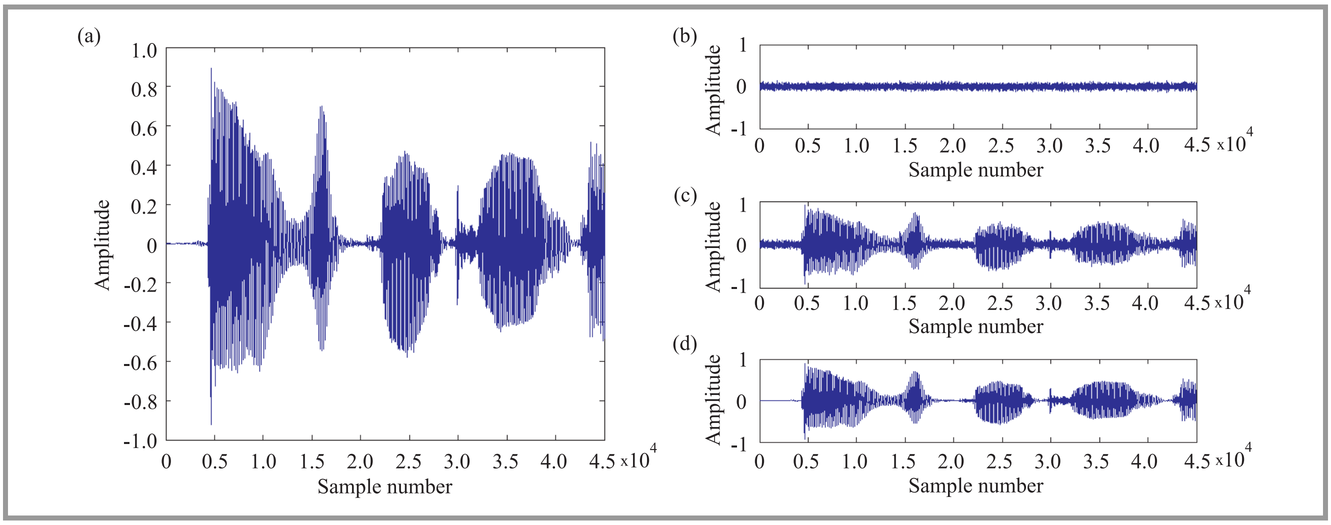

Fig. 1. Plots of (a) clean signal, (b) low level noise signal, (c) noisy signal and (d) restored signal.

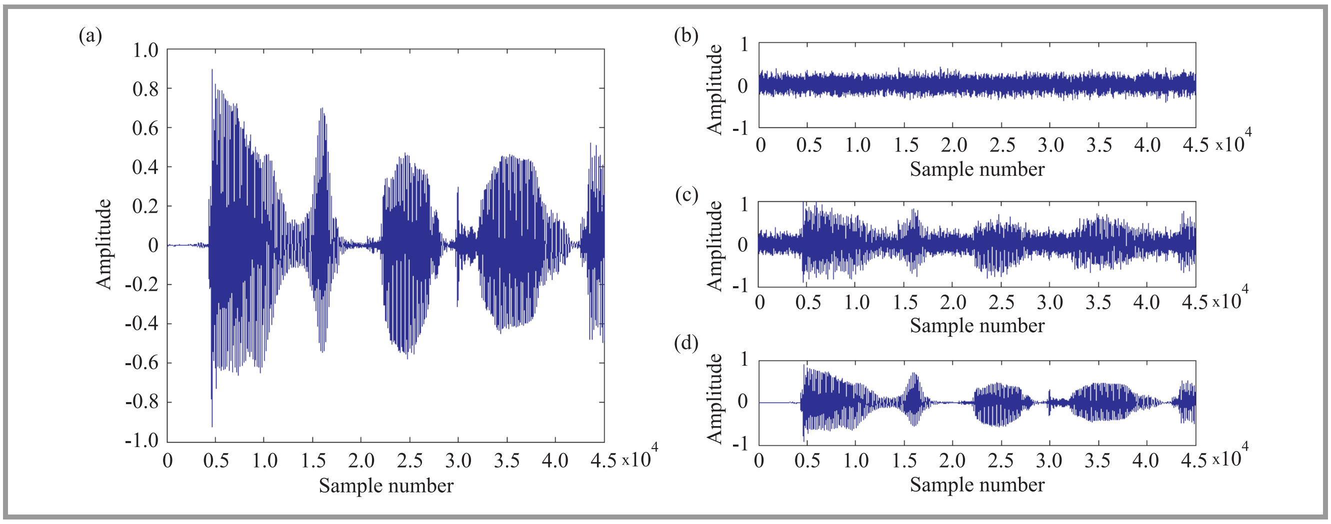

Fig. 2. Plots of (a) clean signal, (b) low level noise signal, (c) noisy signal and (d) restored signal.

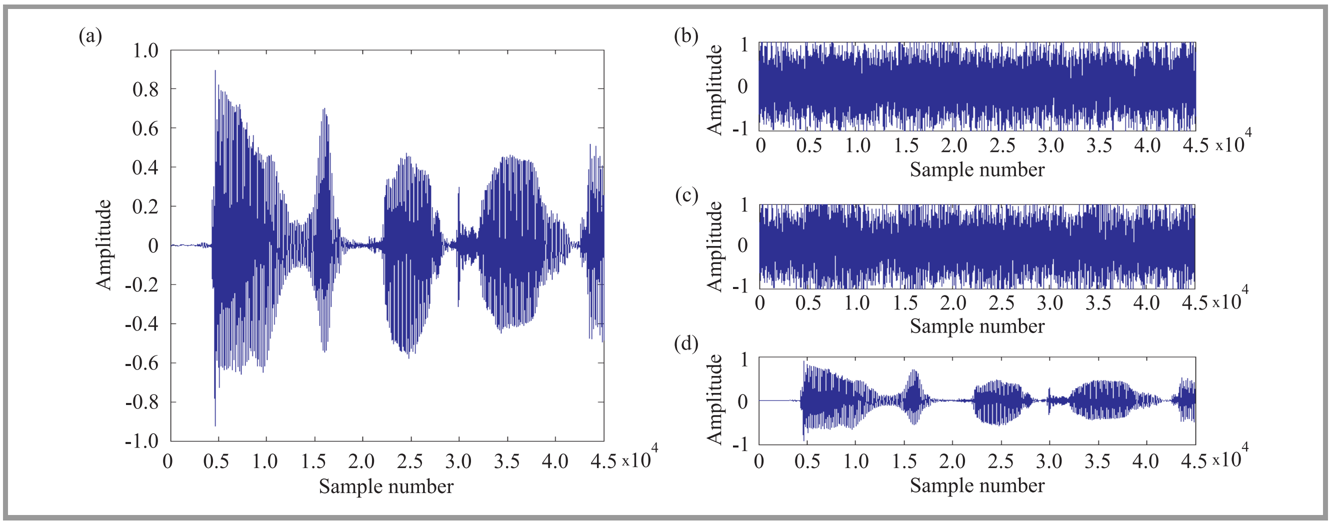

Fig. 3. Plots of (a) clean signal, (b) low level noise signal, (c) noisy signal and (d) restored signal.

the proposed algorithm removes more colored noise without removing the relatively low amplitude speech signal over the entire speech spectrum.

4.2. Listening Test Results

The human listener does not believe in a simple mathematical error criterion. As such, in order to confirm the effectiveness of results obtained from simulations for the proposed method, subjective listening experiments were carried out with clean speech signals and different noise levels. The sampling frequency for all recordings was 8 kHz. 12 persons took part in the listening tests carried out to determine subjective quality and intelligibility of speech enhanced by our method. Eight of the participants are radio broadcast professionals who has about 8 years experience in both analogue and digital speech processing and are in their early thirties. Furthermore, four students working on digital speech processing area and in their twenties participated in the test.

Participants were told to choose the signal they preferred from the ACF-based and conventional SS approaches, as well as choosing according to how intelligible and quality the signal is. The results of our test for residual noise for real-world low-level noise shows that 6 persons preferred ACF approach, 3 persons preferred conventional SS approach, while 3 persons are indifferent. In addition, for residual noise for real-world medium level noise, results show that 8 persons preferred ACF approach, 3 persons preferred conventional SS approach, while 1 person is indifferent. Furthermore, test for residual noise for real-world high-level noise shows that 10 persons preferred ACF approach and 2 persons preferred conventional SS approach. Table 1 shows percentage representation of the residual noise result obtained.

Table 1
The test results for residual noise

Noise type	ACF based MBSS [%]	Conventional SS [%]	Indifferent [%]
Low level	50	25	25
Medium level	67	25	8
High level	83	17	0

Table 2
The test results for speech distortion

Noise type	ACF based MBSS [%]	Conventional SS [%]	Indifferent [%]
Low level	67	25	8
Medium level	83	17	0
High level	92	8	0

The results of test for speech distortion for real-world low-level noise show that 8 persons preferred ACF approach, 3 persons preferred conventional SS approach while 1 person was indifferent. In addition, results of test for speech distortion for real-world medium level noise shows that 10 persons preferred ACF approach, 2 persons preferred conventional SS approach. Furthermore, test for speech distortion for real-world high-level noise shows that 11 persons preferred ACF approach, 1 person preferred conventional SS approach. Table 2 shows percentage representation of the speech distortion result obtained. These results show that the proposed ACF based method outperforms the conventional SS approach.

5. Conclusion

This paper has presented a novel Multi-Band Spectral Subtraction method for enhancing signal corrupted by noise. The introduction of ACF prevents both over and under subtraction as well as signal distortion. In addition, listening test results show that the proposed method performs better than the conventional SS approach. Our approach maintains high signal quality and offers positive improvement that consistently outperforms the conventional spectral subtraction approach for all SNRs observed with no adverse effect on the processed signal. The improvement is because the non-uniform effect of colored noise on the signal spectrum is taken into consideration. This results in a comparatively higher SNR.

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Paper

ID Layer for Internet of Things Based on Name-Oriented Networking

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Abstract—Object and service identification is considered as one of the main challenges in the field of Internet of Things (IoT), which can be solved by the introduction of the so called ID (IDentifier) layer. The objective of this layer is to expose IoT objects and services offered by them, to users. Common approach for ID layer is to create it in overlay manner, on the top of existing network. This paper presents a novel architecture of the ID layer, which is characterized by embedding ID layer functionality into the network plane. Moreover, this approach takes advantage of the Name-Oriented Networking (NON) paradigm. To gain easy access to the IoT objects and services, as well as native support for multicast service, human readable ID-based unified addressing with hierarchical structure was exploited. Additionally, in-network caching of forwarded IoT data, inherited from the NON, helps to reduce total network load and supports applications during collaboration with energy-constrained sensors. Such sensors may enter sleep mode to save energy and then the network nodes can serve requests for sensing data, arrived from applications, by using data stored in nodes' cache. The paper shows the concept of NON-based ID layer and describes functional architecture of network node paying attention on modules and mechanisms related with ID layer functionality. Primary ID layer processes, i.e., object/service registration, resolution and data forwarding are explained in detail. Moreover, the ID-aware network node was implemented on Linux-based platform and tested to check its forwarding characteristics. The tests showed the performance of the of ID network node in data plane operations, which are the more sensitive for scalability issues.

Keywords—Future Internet, ID-based routing, ID layer, Internet of Things, Name-Oriented Networking.

1. Introduction

Internet of Things (IoT) is considered as one of the main trends for further evolution in the area of information and communication technologies. IoT refers to a global network infrastructure linking a huge amount of everyday things, i.e., physical and virtual objects from the surrounding environment, which can communicate between them without human interaction. In IoT, objects are active participants of network ecosystem – they can recognize changes in their surroundings, share information about those changes or detected events with other network members, and perform appropriate actions in an autonomous way.

The open question in IoT research is identification and accessing of the objects and services offered by them, as well as how to bind objects/services to machine addressable and identifiable names [1]–[3]. These issues can be solved by creation of so-called ID (IDentifier) layer, common for all IoT devices. ID layer aims to expose objects and their services in unified way, and should be separated from the IP layer in order to avoid the limitations of IP addressing structure (i.e., no context or location awareness).

The problem of naming and addressing is recently widely investigated in the context of efficient content delivery through the Internet. Solutions which refer to Name-Oriented Networking (NON) model, as Content Centric Networking [4], change the "host-centric" paradigm of the current Internet, in example host-to-host communication, into a "content-centric" paradigm, which treats delivery of content as a primary communication primitive. NON-based architecture seamlessly supports identification, resolution and delivery of content.

In this paper a novel architecture of ID layer, which exploits features of NON for IoT purposes is proposed. Such a solution deals with the registration of object and services as well as the search and delivery of the information related to them. The idea is to include the ID layer into the network level and offering NON network facilities as, among others, in-network caching of IoT data, ID/location separation and support for multicast.

Basically, the proposal is a hierarchical addressing of objects following their physical location. This addressing also contains services offered by objects or groups of objects. The requests of data by the applications as well as the information from objects and/or services are sent through appropriate hierarchical tree. The nodes in the tree are able to cache the data for further requests during the validity period of the data. Over this time, new requests will be served from the nearest node that cached the data. This way, the request and data frames do not need to transfer the whole network (what avoids overload) and data are provided in a short time. Moreover, sensors may go on sleep mode for saving energy consumption, whereas sensing data are still available for applications.

In an intelligent house each room has many objects and the objects offer services to be used by applications in the house, the energy control application decides when to run the radiators located in each room. The objects are attached to the network node and the object and the services are addressed in the network. Then, the network can cache information given by, i.e., humidity meters in ambient with flowers or light sensors in order to avoid constant operation of sensors/actuators.

The paper is organized as follows. Section 2 presents a brief review of approaches for IoT ID layer. Section 3 explains applying the NON concept for creation of ID layer. Section 4 describes proposed ID layer architecture and details of ID-based routing. Performance tests results of prototype implementation are shown in Section 5. The paper is summarized and concluded in Section 6.

2. Related Works

The need for introduction of ID layer to communication stack is outlined by several current research projects which focus on the definition of the IoT architecture (for example FP7 IoT-A [5]). Such layer should perform identification tasks of IoT objects and services, regardless of their network localization.

Approaches for ID layer proposed so far can be divided into two groups, according to the way the separation between network locators and identifiers is assured. The first group assumed implementation of IoT objects identification inside of the application layer and realization of registration and resolution processes for IDs by using distributed databases. An example is the Ubiquitous Code (ucode) proposed by Koshizuka and Sakamura [6].

The ucodes are IDs of the objects that are created as unique numbers with a fixed length of 128 bits. Ucode ties virtual object with the thing, however without any correlation between characteristics and meaning of the object and value of the number assigned to it. Such relationship between ucode value and information about object which is linked with it, is recorded in distributed database created by resolution servers with hierarchical structure. The ucode approach implies, that terminals with installed the ucode client library have access to resolution servers' infrastructure. When the terminal reads the ucode, it has to query the resolution servers to obtain context represented by this ucode.

The second approach assumes introduction to network a new layer, what improves efficiency of messages transfer cause decisions during forwarding process can be made taking into account the ID. Such approach is represented in Veil-VIRO [7] and MobilityFirst [8], [9].

The Veil-VIRO solution [7] introduces a uniform convergence layer on the top of the link layer to ensure connectivity for large number of heterogeneous physical devices. This convergence layer provides support for underlying networks with dynamic structure and various layer 2 technologies, including both Ethernet-based as well as non-Ethernet solutions. The Veil-VIRO concept relies on structured *virtual ids* (vid) used by the convergence layer [10]. The vid address space contains representation either physical (i.e., layer 2) identifiers like Ethernet MAC addresses etc. and identifiers related with higher layers (for example IPv4/IPv6 addresses or flat-id names used at application level). The end hosts' vids have special structure and are created as follows. The first part of the vid, so called host-node part, is L-bit long and indicates VIRO switch (host-node), which given end host is directly attached to. The remaining l-bit long part is used to identify the end host in a set of end hosts connected to the same host-node, in example with the same L-bit prefix.

In VIRO a structured virtual id space is used not only for object address resolution, but also for routing and forwarding purposes. VIRO routing is based on Kademlia-like DHTs (Distributed Hash Tables) [11]. However, in contrary to traditional DHT approach, which assumes end-to-end connectivity and uses IP layer routing and look-up mechanisms, the VIRO must build end-to-end connectivity by itself, using to this aim layer 2 connections established between VIRO nodes.

MobilityFirst [8], [9] assumes that each object is distinguished by a Global Unique Identifier (GUID). The GUID is a string which comprises two parts: object owner's Public Key and value of hash key calculated for the object. The GUID is assigned to the object without any relationship with object's network address and/or location. MobilityFirst proposes to utilize a logically centralized Global Name Resolution Service (GNRS) in order to store information about mapping between object's GUID and its network address. GUID layer is on the top of the network layer and features flat structure. MobilityFirst assumes that network nodes forward data according to hybrid GUID/network address routing: routers can deliver packets considering packets' GUID only or using GNRS to discover network address associated with given GUID. Moreover, in order to allow applications to search objects, MobilityFirst requires implementation of external name assignment service, which is responsible for assigning and publishing object's GUID jointly with its semantic description.

In conclusion, presented solutions do not affect network technology and relay on overlay systems, particularly for discovering and accessing objects and services in IoT.

3. Using Name-Oriented Networking Concept for ID Layer

Name-Oriented Networking, exploited in Content-Centric Networking (CCN) [4], and its successor Named Data Networking (NDN) [12], constitutes a new paradigm for solving naming and addressing aspects in the Internet. It assumes, that network is aware, what data (content) are requested by users and transferred through nodes. When the user wants to download given content, it sends to the network an Interest packet that identifies the required data by its name. Next provider's application, which registered for a given name prefix, sends a Data packet as a response to this Interest. When the Data packet traverses through the network, network nodes cache it for serving forthcoming Interest messages.

In this paper an exploit the NON concept for creation of IoT ID layer is proposed. The main idea based on human readable IDs for objects and services. Also network nodes are labeled with such ID, and the structure of IDs is or-

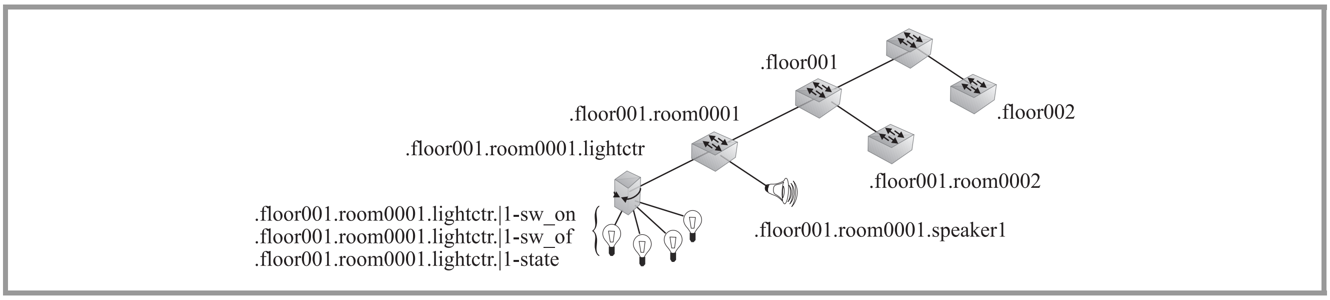

Fig. 1. ID naming example.

ganized in hierarchical manner, which allows a tree-based ID routing, i.e., the data frames are transferred, according to ID carried in their headers, by established trees in both upload and download directions.

The IDs are created and managed taking into account the location of each IoT object. Name (ID) of every object, service or network node is formed by 8-byte ASCII-based word compatible with ISO 8859-1 standard [13]. The address (locator) of object/service is created as a chain of all the names, concatenated by a dot, from the root (which is marked as "∗") to given object/service. Figure 1 presents an example of address of the light controller (ID: lightctr) in the first room on the first floor (.floor001.room0001.lightctr) with exemplary services related with light 1: "switch on" (.floor001.room0001.lightctr.l1-sw_on), "switch off" (.floor001.room0001.lightctr.l1-sw_of) and "check status" (.floor001.room0001.lightctr.l1-state). Using human readable addresses for objects and services provides flexible and convenient way for creation multicast services. It is assumed that two symbols are reserved in naming: a dot "·" in order to build hierarchy essential in ID-based routing, and a star "∗" for multicast calls. Proposed hierarchical naming scheme and ID routing simplifies multicast connections. To address message to group of objects on given region, i.e., "switch on" all lights on the first floor, ID of the form: .floor001.∗.lightctr.∗-sw_on could be used. It is assumed that the object indicated by the full address can recognize requested service and takes the adequate action, otherwise it will return error message.

The forwarding nodes compare the ID from frame header with the address of the node and based on comparison result decide on which port forward the frame. Similar to CCN/NDN, network nodes can store forwarded data in cache, and then future requests from applications are served using node caches. This feature can bring benefits in IoT scenario if common behavior of small, battery-powered sensors is considered. These devices may work at active mode and serve requests received from applications, or may enter into sleep mode turning off both the receiver and transmitter to save power. In-network caching allows network nodes, which forward IoT data, to keep the results of sensing. In this way, the applications have access to them all the time, also within the period when the sensor is in a sleep mode. This characteristic is particularly profitable in scenarios, which assume existing of many different sensors in the network, where each sensor may enter into energy saving phase in different periods [14].

Embedding the ID layer into the network level offers awareness about IoT data to the network nodes. In this way, the network nodes are responsible for crucial operations for IoT: registration of objects and services available in the network, and retrieval information about the registered elements to the applications that ask for it. On the other hand this approach does not exclude attaching of IoT devices which are not aware of ID layer as, in example devices based on 802.15 standard family. In that case, the connected objects or applications would require performing appropriate encapsulation operations in the so-called object controller (see Fig. 2). This approach is in conformance with ETSI M2M functional architecture [20], where M2M devices are divided into two groups: first are those which have enough resources to implement encapsulation mechanisms and they interact directly with network nodes, and second are devices with constrained resources which connect with network nodes via object controllers (i.e., ZigBee sensors). This architectural approach is shown in Fig. 2.

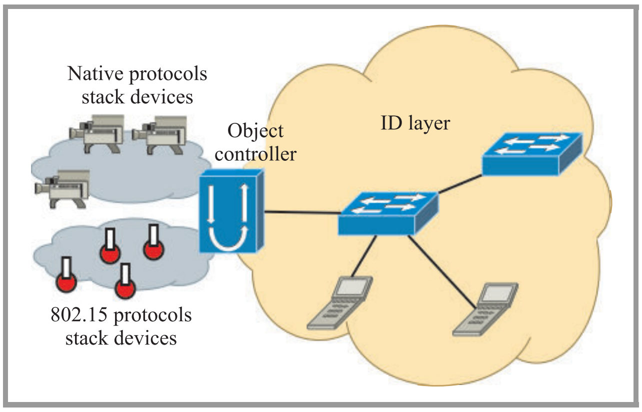

Fig. 2. Interworking between IoT devices connected to ID layer capable network nodes.

Proposed architecture for the ID layer implies the following three phases of data distribution:

Registration and publication – objects register itself, together with all the services that they offer, in the closest network node. It is the ID layer aware network node, which the registering object is directly connected to. After registration, object and services are available for applications connected to the system.

Resolution – the applications can ask for objects and services in the whole network (by sending resolution request to the root node) or in particular segment of the network (by sending resolution request to selected network node).

Data delivery – IoT-specific caching in network nodes improves the data gathering as well as delivery process. Since the data is placed closer to application servers, response time for application requests can be reduced, and also limit amount of traffic in the core network. When a sensor sends any information to an application, the information is cached in the network nodes, which responds fast to future requests of these data (during the validity time of the data) allowing that the sensors go on sleep mode. It is worth noting, that in contrary to the content data, significance of IoT data is restricted, therefore for IoT purposes an additional parameter has to be introduced: the validity time of the data. Its value is configurable and strongly depends on the place and the context of object usage. In the context of temperature control, some scenarios require validity time to be set to value of several minutes [19] whilst others may require higher dynamicity and, therefore, validity time should have lower value.

Summarizing, the most outstanding features of the proposed approach for ID layer are as follows. First, thanks to human-readable hierarchical naming scheme, our solution integrates addressing of IoT objects and services. By creating network address as a concatenation of IDs, it ensures separation of ID and locator while using one unique addressing structure. Involvement of mechanisms inherited from Name-Oriented Networking approach improves forwarding of ID layer frames as well as enables implementation by IoT objects different energy efficient operating modes. Proposed hierarchical ID-based routing considerably simplifies multicast communication at various scopes. Furthermore, characteristics of IoT objects/services are location-specific, which facilitates fundamental IoT processes as object/service registration and publication, and allows distribute them among many network nodes.

Other proposition for exploitation of NON concept for IoT purposes is presented in [15]. The authors propose a CCN-oriented service platform to implement IoT services in the network. Similar to this solution, they exploit hierarchical names for services and name tree to determine how *Interest* and *Data* messages should be treated. However, the platform proposed in [15] is designed as over-the-top solution above the network layer, and based on UDP/IP service.

4. ID Layer Architecture

In Fig. 3 the functional model of an IoT-aware node which complies with proposed ID layer architecture is shown. It contains three main planes:

- resolution and reachability – exposes registered objects and services to users and manages the reachability of the objects and services,
- naming and registration – aims at assigning unique, hierarchical IDs to the objects connected to the network,
- data forwarding – provides forwarding and routing rules for ID-labeled frames.

Taking into account that each network node contains interfaces for each plane and the network has hierarchical structure, all IoT-related operations, i.e., registration, publication, resolution, data request and data delivery, are managed only locally in the nearest network node. This results in a high flexibility and manageability and improves the response of the system when the number of handled things scales.

Detailed operations performed by the network node related with ID layer functionality and describe the exact functionalities of the blocks are presented in Fig. 3. Even when Fig. 3 shows security/privacy blocks, their functionalities are not described in the text since they are out of the scope of this paper.

When a new object is connected to the system or a new service is created, this object/service registers by sending a *Register* message to the edge node it is attached to. The *Register* message contains the name of new object/service jointly with its description, which will be used during resolution operations. When the node receives this message, it checks validity of the name and, if the name is correct, it performs a publication action by storing the name and information about newly connected object/service in the *Object/Service* register.

In the case when the ID is already registered or contains any reserved character, the *Register_failed* message is returned to the object. Otherwise, the *Register_accepted* message with the complete chain of concatenated IDs, which constitutes an address of the new object/service, is sent back to the node's port by which the *Register* message arrived. Since the registration and publication process is performed only in the edge network node, the *Register* message is not transferred to further network nodes. A newly attached object registers not only its own ID but also the offered services. These services are associated with actions taken by the object. Note that given action could have several different IDs for distinguishing the context in which the action is taken. It is important in case of controlling the same set of objects by different applications (i.e., door/window locking controlled by both user commands and fire monitoring). Also, given service ID may trigger aggregated actions in the object, for example switching on all the bulbs in one lamp.

The full address of new object or service is created as concatenation of the full address of the network node the new object/service is attached to, and the ID of this object/service. Address assignment is responsibility of the *ID naming* module. That structure of hierarchical routing

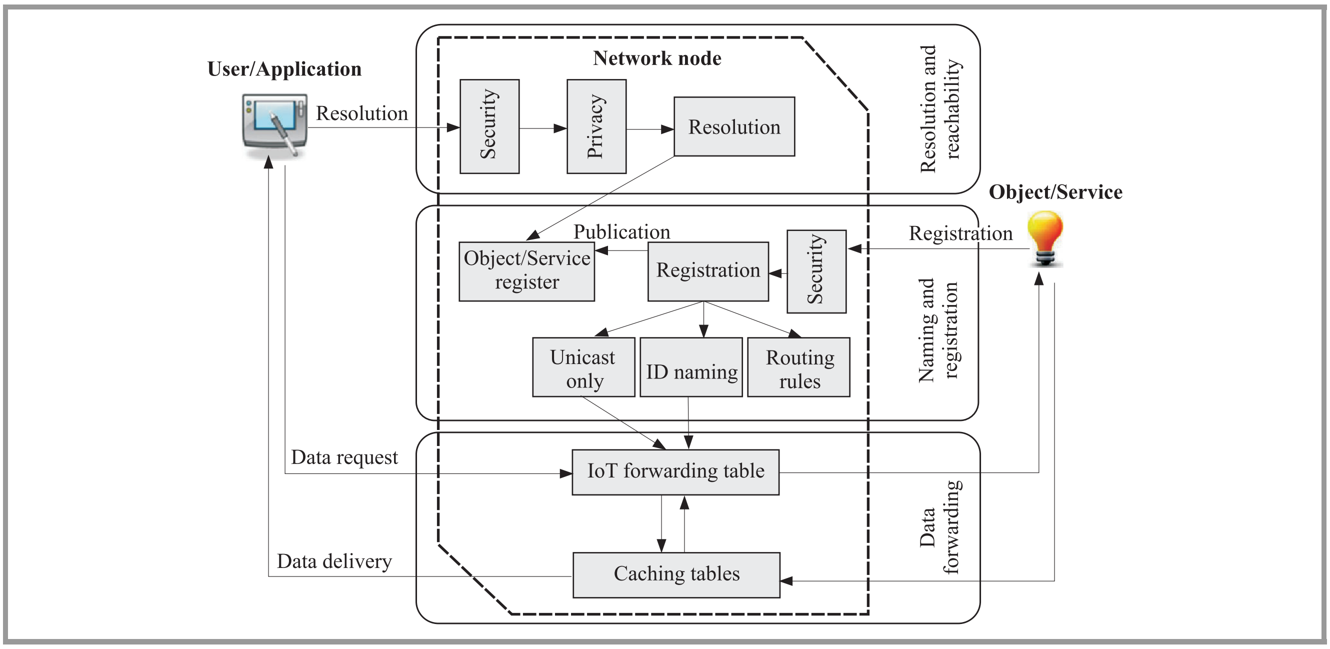

Fig. 3. Functional blocks of ID layer network node.

tree is delimited up to 64 levels, therefore the network permits addresses which contain at most 64 concatenated identifiers, where each ID being 8 bytes long. Taking into account that the maximum size of the payload field of an Ethernet frame is 1500 bytes, in case of the longest allowed object/service address, there are still almost 1000 bytes available for data. Such size of the available payload is sufficient for most IoT applications, which mostly send and receive short messages with control instructions, remotely sensed information or actuator commands. By limiting number of hierarchy levels, the problem of unbounded, variable-length naming, which is considered as one of the scalability issues related with NDN approach, is avoided [12].

When applications want to discover objects and services available in given node (i.e., in the second floor), they send a *Resolution* message to it. The node, in response, returns sequence of *Resolution_response* messages, where each message corresponds to one of the objects and services stored in node's *Object/Service* register. The *Resolution_response* message contains fields that hold the full address of the object/service as well as a description of this object/service. Note that such a description should be sufficiently extensive in order to make feasible easy manage of the services. At the same time, the description of the objects can be uploaded by the objects when any characteristic of the object/service changes. Additionally, the applications receive *Resolution_response* messages with addresses of the network node's child nodes. These addresses can be used by application for discovering all the objects and services existed in the sub-tree of the network node, i.e. in all rooms in the second floor.

The second way to obtain information about objects and services available in given domain is to send to the network a multicast *Resolution* message for discovering all registered objects/services i.e., in one room or at one floor. Using *Resolution* message addressed to the root node, the application can get information about objects and services existed in the whole network.

Note, that from application point of view, the resolution process is performed locally because the applications can know where desired object or service are located (i.e., in floor1.room1). This characteristic, which is inherited from IoT features, was exploited in this system. Moreover, it is assumed that it should be investigated to cope with mobility issues.

There is a multicast flag in each ID layer message header, which indicates whether the message is multicast-enable or not. If the multicast flag in the *Register* message header is not set, it points out that it is not allowed to access given object or service in a multicast manner (i.e., with using "∗"). Information about exclusion of the object/service from multicast service is stored in the *Unicast only* module, which precludes that future multicast requests will be transferred to this object/service.

The *Routing* rules in the network are directed to maintain stable hierarchical addressing for routing packets. When one node is added or deleted to the network, then *Routing rules* modules should change for maintaining appropriate forwarding tables in data forwarding plane. The same occurs whenever one network node changes the position in the hierarchical tree.

The Data *Forwarding* plane, responsible for transferring ID-layer frames according to ID-layer header and rules defined by upper planes, is located on the bottom (Fig. 3). The network node begins frame forwarding process by checking, in the frame header, the address length and next reading appropriate number of concatenated identifiers (as the address itself). If the frame's destination address equals the node's address, then the frame is directed, according to the message type, to the Registration or Resolution module inside this node. Otherwise, the forwarding decisions are taken using the *IoT forwarding table*. This table stores IDs of objects and services registered in the node together with the multicast flag and the node port they are attached to.

The forwarding rules applied in *IoT forwarding table* are as follows. The prefix (i.e., upper part of hierarchical address) of the frame destination address do not match with the network node address. It means that the frame is addressed to object or service located in the other sub-tree in the hierarchy and therefore it is transferred to the parent node. The prefix of the frame destination address fits in with the network node address, taking into account the multicast symbol also. The frame is addressed to object or service located in the sub-tree rooted at this network node. Then, the next ID in the message destination address (according to the node hierarchy level) is analyzed, and:

- the frame is forwarded to the child node, whose ID fits in with the destination address next ID,
- if the next ID of destination address contains the multicast symbol, then the frame is forwarded to all child nodes except those for which a multicast exclusion entry is stored in the Unicast only module,
- if name of any child nodes does not match with the next ID in the frame destination address, the frame is discarded.

In parallel to forwarding tasks, the network node executes additional caching actions, which are invoked for two types of messages: *Data* and *Request*. Each network node contains two caching tables. The *Data Caching Table* handles the Data messages and stores: the source address of the object or service, the data related with this object/service and its validity time. Whenever the *Data* message with given source address and longer validity period arrives to the network node, an appropriate record in the *Data Caching Table* is updated. Additionally, sanity operation could be performed in order to erase expired entries and avoid problems with oversized table.

Once the *Request* message is received by network node, the node at first finds out if the requested information is available in the *Data Caching Table*. It checks the following conditions: whether the message destination address converges with an entry in the *Data Caching Table*, and whether the validity time of data found in the *Data Caching Table* is longer than the requested validity time carried in the *Request* message header. If the above conditions are met, the request is handled using relevant *Data* message from the table. Note that the synchronization between network nodes, objects and applications, which is required for data validity time verification, does not need to be higher than hundreds of milliseconds. Therefore, simply using of Network Time Protocol should be enough.

Another caching table in the network node is the *Request Caching Table*. It is used to store Request messages which are not served from the *Data Caching Table*. Such messages are transferred through the output port according to message destination address, and corresponding entry is created in the *Request Caching Table*. This entry contains the address of requested object/service and the port from which the *Request* message arrived. When the *Data* message comes to the node, as the answer to the *Request*, a record with the source address of this message is searched in the *Request Caching Table*. Next the message is forwarded to the port indicated in the record and the entry in the table is deleted. In the case when the message source address is not found in the table, network node discards received *Data* frame.

Records in the *Request Caching Table* are erased also when the validity time of given record expires. Moreover, in order to maintain acceptable size of the *Request Caching Table*, the network node may execute sanity operations to avoid persistence of entries in the table during a long time, even if corresponding requests have not been served yet. Thereby, even if the network nodes have limited resources, they are still able to handle large-scale number of flows [12]. On the other hand, some *Request* messages are not cached in the *Request Caching Table*, because their validity time is set to 0 as applications do not expect a response for them. Such situation may occur, for example, when *Request* message carries an action command addressed to actuator.

5. Prototype of ID Layer Node

To validate and test the proposed approach, the ID-layer functionalities of the network node were implemented on the top of Ethernet technology from scratch. Specific Ethertype value for IoT frames were to defined to distinguish ID-layer frames from legacy Ethernet frames. All frames with such an Ethertype are handled by the network node according to the ID-based forwarding rules.

All the necessary modules and procedures required to registration and resolution of IoT objects and services, as well as IoT data forwarding using an ID-based routing, have been developed in a Linux-based server (version 2.6.17 of kernel) with processor Intel Core 2 Duo Desktop Processor E8500 3.16 GHz. The modules responsible for registration and resolution processes were implemented in the user space, due to its flexibility and ease of use, whereas data forwarding modules were implemented in the kernel space to achieve high forwarding efficiency.

The testbed assumes a ring topology, as recommended by the benchmarking methodology for measuring network interconnect devices [16], and consists of one server, with installed ID layer modules, connected to the tester by two 1 Gbps Ethernet links. To generate and receive the IoT traffic with ID layer header the Spirent TestCenter tool, equipped with CM-1G-D4 card was used.

Next the performance tests for understanding the forwarding characteristics of the implemented network node were run. The tests conducted were two-fold: first the influence of the size of the *Request Caching Table* in Data frames forwarding performance was analyzed and secondly, forwarding throughput of *Request* frames was checked. In the first case, a *Request Caching Table* with growing number of entries, i.e., from 1,000 to 100,000 requested services was prepared, so that in the network the number of streams is in this range (up to 100,000) could be considered. Note that current versions of OpenFlow tables can handle up to 100,000 parallel flows [17]. Afterwards, a stream of *Data* messages and calculated the throughput for different *Request Caching Table* sizes was generated. Throughput was defined as the maximum rate of frames forwarded by the network node without any losses.

When the network node received a *Data* message, it searched the source address of the message in the *Request Caching Table*, and next forwarded the message to the output port, which was pointed out in the table entry. Through this output port the message was re-sent to Spirent TestCenter. The validity time of *Data* messages was set to 0, to exclude influence of caching them in the *Data Caching Table*. Size of Data frames was equal to 64 bytes.

The following test measured the forwarding throughput of *Request* messages. For this, a stream of *Request* messages in the Spirent TestCenter was generated. The requested service was the same one in all the messages and was not cached in the *Data Caching Table*. In this case, when the network node received the *Request* message, it did not find requested service in the *Data Caching Table*, therefore destination address of the message is compared with node address and the message is transferred to the output port, to which Spirent tool was attached in a ring topology. Since the validity time of the *Request* message was equal to 0, the message was not cached in the *Request Caching Table*. Also in this case, the *Request* frames were 64 bytes long.

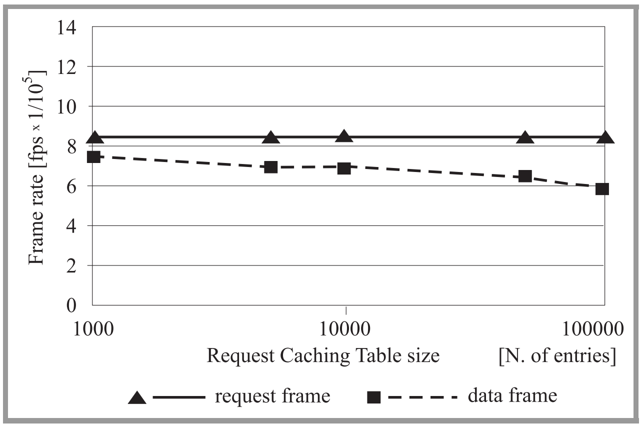

Fig. 4. Throughput of Data and Request frames for increasing size of Request Caching Table.

Figure 4 presents the throughput of *Data* messages for different size of *Request Caching Table*. When the number of entries in the table increase, the *Data* frame throughput slightly decreases. This does not occur for *Request* messages since *Request* forwarding operations did not involve the table during this test (validity time=0), which may be observed in the *Request* forwarding results presented in the same figure. The throughput of *Data* frames is visibly lower than the throughput of *Request* frames, even for small size of *Request Caching Table*. This is because, in the presented test conditions, the *Data* messages required more processing operations in the network node than *Request* messages. Note the ID layer node was implemented without any optimization in *Request Caching Table* searching operations (the table is created using simple ASCII hash function).

The main conclusion of Fig. 4 is that also for bigger *Request Caching Tables*, the forwarding throughput of developed ID-aware network node is in the range of software IP routers – in [18] the authors show, that, in the case of minimum-size Ethernet frames, software router based on high-end PC can forward up to $6 \cdot 10^5$ packets/s. Note, that there are no errors in the network node performance for the forwarded *Data* and *Request* frames for flow rates fewer than the throughput value. Therefore, it could be affirmed that the network node for up to 100,000 entries stored in *Request Caching Tables* works properly.

6. Conclusions

Internet of Things is a network of "smart" objects, which autonomously can find and cooperate with other members of the network. For this purpose, a device-independent abstraction layer, called ID layer, is introduced into the protocol stack.

In this paper, the solution for ID layer, which bases on Name-Oriented Networking paradigm, was proposed. Contrary to many proposals for the ID layer presented in literature, which do not introduce any changes into network plane and build the ID layer on top of it, IoT awareness into the network was introduced. Such approach enables to avoid overlay solutions and helps to achieve high efficiency and simplification for IoT related operations as object/service registration, object/service searching and delivering of IoT data.

This proposition of ID layer involves a Name-Oriented Networking addressing scheme for objects and services offered by them, together with hierarchical ID-based routing. The ID-based routing introduces new capabilities in IoT networks, because it is characterized by separation between identification and location: particular names (words) of an ID indicate entity, virtual or physical, whereas the ID as a whole (i.e., the chain of words) indicates its current localization in hierarchical tree. This provides flexible and convenient access to IoT resources.

Moreover, awareness of IoT data at the network level allows for introducing data caching functionality in network nodes. It improves effectiveness of network utilization and makes feasible cooperation between IoT applications and sensors with applied energy consumption saving mechanisms.

A prototype of the ID-aware network node using server with Linux operating system was developed. The implementation is based on standard IEEE Ethernet technology, resulting that it can coexist in network with nodes which have implemented only legacy protocol stack. Such nodes are unaware of ID layer messages and the coexistence is possible through tunneling the IoT traffic between two contiguous ID-aware network nodes by applying standard tunneling technique, for example IP-tunneling.

The results of experiments on performance of implemented ID-aware network node for forwarding ID layer frames, shows that proposed solution achieves acceptable throughput, similar to software IP router, even when the *Request Caching Table* has significant size. Nonetheless, it was clear that forwarding performance of ID-aware network node comes down when the number of IoT data flows increase. However, this performance reduction does not seem to be a problem for the correct running of the prototype, so it can be concluded that the solution is acceptable for intra-domain routing, where scalability issues are not crucial.

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Paper

Agent-based Optimization of Advisory Strategy Parameters

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Abstract—In this paper, an application of Evolutionary Multi-agent Systems (EMAS) and its memetic version to the optimization of advisory strategy (in this case, Sudoku advisory strategy) is considered. The problem is tackled using an EMAS, which has already proven as a versatile optimization technique. Results obtained using EMAS and Parallel Evolutionary Algorithm (PEA) are compared. After giving an insight to the possibilities of decision support in Sudoku solving, an exemplary strategy is defined. Then EMAS and its memetic versions are discussed, and experimental results concerning comparison of EMAS and PEA presented.

Keywords*—*global optimization, memetic computing, multi-agent computing.

1. Introduction

Decision support constitutes a broad range of different techniques, mostly related to artificial intelligence, aimed at helping the human (decision-maker) in different activities, such as choosing the most feasible strategy for investing in financial instruments, performing a diagnosis of a faulty system or predicting product revenue in the market [1].

Sometimes, a valuable advice may be given using a predefined model that will help in simulating or solving a certain task. Such model may become a source of knowledge, straightforwardly supporting the user in performing certain decision-making tasks. Such a model may be proposed, e.g., in the form of a set of equations constructed by an expert, but also, it is possible, that may be constructed in an automated way [2].

As an example, the process of optimization of neural network architecture may be mentioned (as neural networks may in a natural way become a part of decision support system and serve as means for solving approximation problems, e.g. classification and prediction, as well as control problems, i.e. management of some process or device). Even though the use of neural networks replaces the necessity to solve the problem in a deterministic way, one still needs to define network parameters, such as its structure, learning coefficients etc., which should be suitable for the given problem. This usually requires carrying out numerous experiments, so it is a very time consuming job and can be performed only by the specialists [3].

At the same time, techniques of evolutionary computation were successfully used to solve difficult search and optimization problems and it was also shown that they may be useful to support search for optimal parameters of a certain model (e.g., optimal neural network architecture). Although the classical evolutionary algorithms can be easily applied to search for optimal parameters of a certain model, additional advantages may be expressed by applying more complex search methods, such as agent-based computing.

Evolutionary Multi-agent Systems (EMAS) proposed by Cetnarowicz [4] and further developed by Byrski and Kisiel-Dorohinicki have already proven as an effective tool for dealing with global optimization problems (see, e.g., [5]–[7]). Moreover, a significant effort has been made, in order to give formal rationale for conducting the search (see, e.g., [8]–[11]) In these systems global control well known from evolutionary-like computing [12] is replaced by a distributed selection mechanism using non-renewable resources. The agents are introduced and removed from the population in the course of reproduction and death actions, influenced by the amount of resources owned by certain agents.

In this paper, an application of EMAS and its memetic version to the parametric optimization of parameters of the advisory strategy is presented. The case study is based on an original Sudoku advisory strategy, helping in choosing correct moves in the course of solving of this puzzle.

In the beginning of this work, several Sudoku advisory strategies are identified, and an original advisory strategy is presented. Later memetic agent-based computing systems are shortly discussed and finally the experimental results concerning the application of the EMAS and its memetic versions to the identification of the strategy parameters are shown and the paper is concluded.

2. Sudoku Advisory Strategies

Sudoku is a worldwide-known number-placement puzzle, in which the user is given the task to fill a 9×9 lattice with digits in such way that each column, row and each of nine 3×3 sub-lattices that compose the lattice contain all of the digits from the range 1 to 9. As a starting point, partially completed lattice is supplied, that usually has one unique solution [13], [14]. Sudoku is a NP-complete constraint satisfaction problem. The proof can be found in [15]. The fact of Sudoku's NP-completeness makes solvers using solely brute-force techniques infeasible.

In this paragraph, dedicated advisory strategies for Sudoku problem are discussed. They should not be treated as ap-

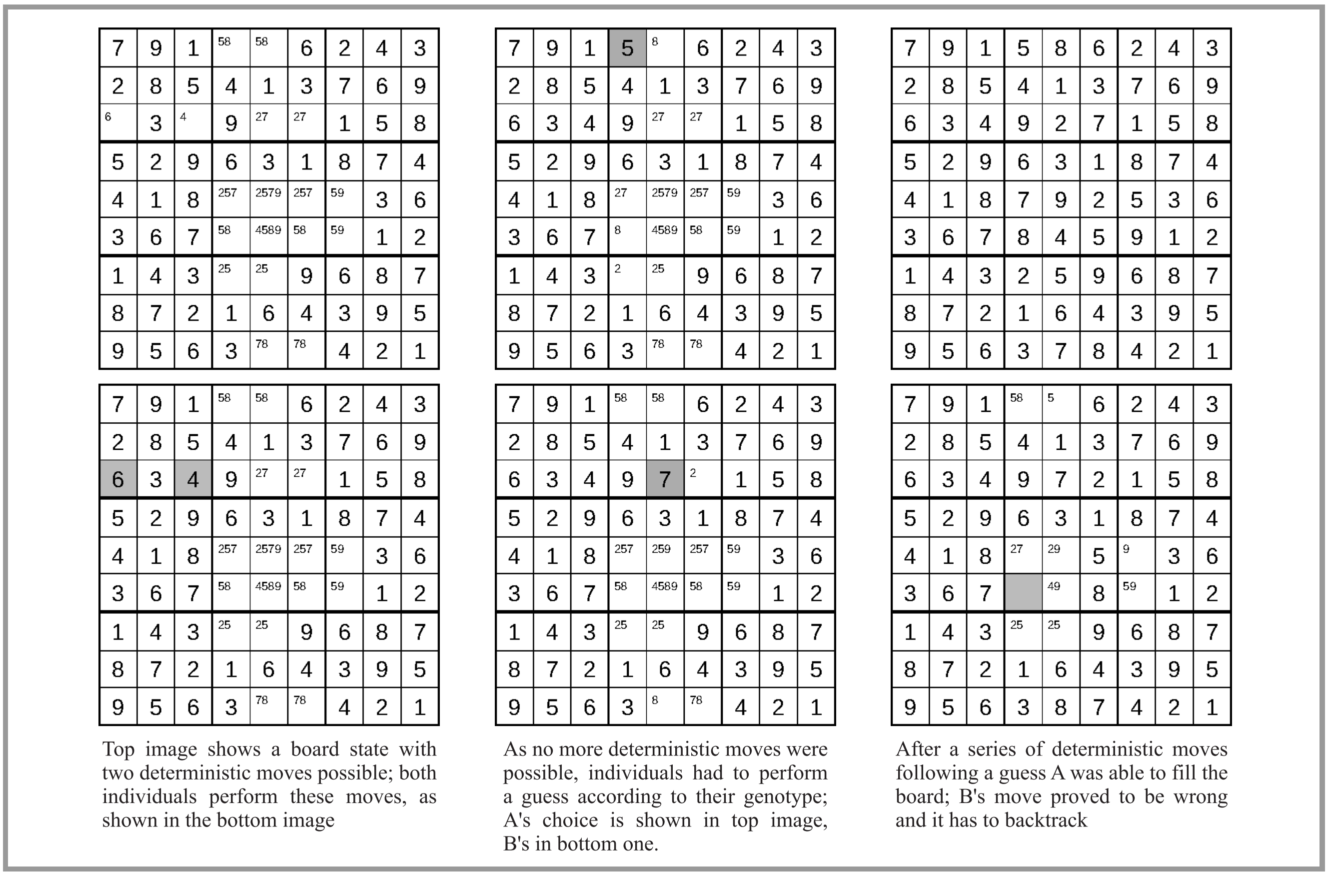

Fig. 1. Example illustrating a portion of board solving process with moves performed by two different individuals, **A** and **B**; small numbers represent $S(p)$ sets.

proaches to solve this puzzle directly, rather that as means for suggesting of the strategy, that may be used by the human. Open-source Sudoku solvers [16] implement various strategies, formulated by Sudoku community, to detect incorrect movements in advance and reduce the number of backtracks [17]. These strategies allow to either exclude some movement possibilities or make a deterministic move to satisfy Sudoku's constraints in a specific board setting. Paragraph below provides a summary of a few popular strategies described in [16], [18].

Naked Pairs – let A and B be the only candidate movements for 2 empty fields in a row, column or 3×3 block. No other empty field within the same unit can be filled with A or B.

X-Wing – let A be a candidate movement in 4 empty fields that are located in the vertices of rectangle. Any other empty field that share row or column with the rectangle's vertices cannot be filled with A.

Sword Fish – let A be a candidate movement in empty fields that share 3 different rows or columns. Any other empty field in each of the rows or columns cannot be filled with A.

The detailed overview of Sudoku advisory strategies is available in [19]. The aforementioned strategies can be also used to assess the hardness of Sudoku boards [17]. Different approach to solve and estimate Sudoku boards using continuous-time dynamical system and Richter type scale respectively is described in [15].

The Proposed Strategy

An original strategy of solving Sudoku puzzle based on the way human usually resolves this puzzle [13] is defined as follows. The strategy is supposed to point out the subsequent field of the lattice to fill it out with one of the feasible digits following there is not known any other movement enforced by Sudoku constraints. Therefore, for each field of the lattice, denoted here as (x,y), for all empty fields located in the row x and column y, and all feasible digits i, the value of the following weight function is computed:

$$W(x,y,i) = a_1 \cdot \mathit{Fill33}(x,y) + a_2 \cdot \mathit{FillRow}(x) + a_3 \cdot \mathit{FillCol}(y) + a_4 \cdot \mathit{Occ}(i)\,, \quad (1)$$

where:

- $\mathit{Fill33}(x,y)$ is the function computing the filling level of the 3×3 block where (x,y) field is located,
- $\mathit{FillRow}(x)$ computes the value describing the filling level of the row x,

– *FillCol*(y) computes the value describing the filling level of the column y,

– *Occ*(i) computes the count of the fields with the number i.

Then the move consisting in putting the digit i into the field (x,y) is made, for the field bearing the extremal value of the function $W(x,y,i)$ (minimum or maximum, depending on the exact definition of the *Fill33*, *FillRow*, *FillCol* and *Occ* functions).

The problem of optimization of the proposed Sudoku advisory strategy may be treated as parametric optimization [20] (maximization in this case) of the function $W(x,y,i)$ depending on the parameters $a_k \in [-3,3]$, $k \in [1,4]$, used to advise the subsequent moves in Sudoku solving. This may be accomplished with an evolutionary approach. In order to do this, the pattern sought is encoded as a following weight vector:

$$[a_1,a_2,a_3,a_4], a_k \in [-3,3], k \in [1,4],$$

and the fitness function is defined as follows as a multiplicative inverse of number of non-feasible decision undertaken by the individual in the course of solving a series of lattices according to the following procedure (see also Fig. 1 for illustration).

1. Make all deterministic moves:

    - A deterministic move is the one that follows straightforwardly the Sudoku rules (in each column, row and block at most one number of certain value can be located, without backtracking or contradictions).

    - For each field p of Sudoku board a set of numbers $S(p)$ is determined, that can be filled into this field without breaking the Sudoku rules.

    - If exists p for which $S(p)$ contains only one symbol s, it is removed from all other $S(\cdot)$ located in the same 3×3 block, column or row.

    - If in the course of reducing $S(\cdot)$ sets, a new set of cardinality 1 is obtained, the procedure is repeated for this new set.

    - The algorithm is finished when all sets $S(\cdot)$ contain only one element or during the actualization of the $S(\cdot)$, no one-element set was obtained.

2. If the board is not solved, make a move according to the current strategy, otherwise finish the move according to the strategy and increase the counter of non-feasible decisions for the evaluated solution.

3. If the board is not solved, go to step 1.

3. Evolutionary Agent-based Computing

In evolutionary multi-agent systems, an agent represents solutions for a given problem. Core properties of the agent are encoded in its genotype and inherited from its parent(s) with the use of mutation and recombination operators. Besides, an agent may possess some knowledge acquired during its life, which is not inherited. Both inherited and acquired information determines the behavior of an agent in the system (phenotype). Assuming that no global knowledge is available and autonomy of the agents, selection is based on non-renewable resource, most often called *life energy* [4]. Thus a decisive factor of the agent's activity is its fitness, expressed by the amount of energy it possesses. The agent gains energy as a reward for 'good' behavior, and looses energy because of 'bad' behavior. Selection is realized in such a way that agents with high energy level are more likely to reproduce, while low energy increases the possibility of death. The agents are located on islands, which constitute their local environment where direct interactions may take places, and represent a distributed structure of computation. Obviously, agents are able to change their location, which allows for diffusion of information and resources all over the system [21].

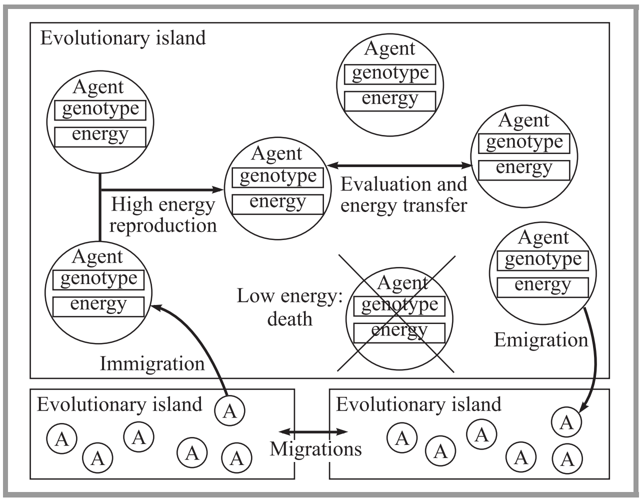

Fig. 2. Evolutionary multi-agent system.

EMAS agents may perform the following actions (see Fig. 2):

- *Reproduction* – performed when the agent's energy raises above a certain level, followed by production of a new individual in cooperation with one of its neighbors, with genotype based on parents' genotypes (crossed over and mutated) and part of energy (usually half of its initial value) also passed from each of its parents.

- *Death* – agent is removed from the system when its energy falls below a certain level, the remaining energy is distributed among its neighbors.

- *Evaluation* – agent chooses its neighbor and compares the fitness of its genotype with its own. In the case when the neighbor is better, it receives part of the agent's energy, and vice versa.
- *Migration* – agent (with some probability) may migrate, then it is removed from one evolutionary island and moved to another (random) according to predefined topology.

Each action is attempted randomly with certain probability, and it is performed only when their basic preconditions are met (e.g., an agent may attempt to perform the action of reproduction, but it will reproduce only if its energy rises above certain level and it meets an appropriate neighbor).
Implementation of Baldwinian and Lamarckian memetics in EMAS is carried out in the following way.

Baldwinian memetics – this implementation is done in a similar way as in classical evolutionary computing: the evaluation operator is enhanced with local search algorithm. The evaluation of a certain individual starts the local search from this individual and returns the fitness of the solution found instead of the original fitness value.

Lamarckian memetics – a dedicated mutation operator is called in the course of agent's life, therefore its genotype may be changed whenever this action is undertaken.

4. Experimental Results

The Sudoku strategy proposed in this paper was evaluated using four hard level Sudoku boards generated by [16]. The generator is assessing the level of difficulty by scoring the hardness of each strategy before and summing total score of movements that constitute the final solution. Although the program provides a vast array of tune settings, they were not used in order not to favor any specific solving strategy. The purpose of examining multiple boards was to exclude the risk of over fitting.
The results have been obtained using a dedicated system implemented with Python technology.
The configuration of the tested systems is presented as follows:

- *common parameters* – normal distribution-based mutation of one randomly chosen gene, single-point crossover, the descendant gets parts of its parents genotype after dividing them in one randomly chosen point, 15 individuals located on each island, all experiments were repeated 30 times and standard deviation (or other statistical measures, such as median and appropriate quartiles for box-and-whiskers plots) was computed; allopatric speciation (island model), 3 fully connected islands, 150 steps of experiment, genotype of length 4, agent/individual migration probability 0.01;
- *PEA-only parameters* – mating pool size: 8, individuals migrate independently (to different islands);
- *EMAS-only parameters* – initial energy: 100, received by the agents in the beginning of their lives, minimal reproduction energy: 90, required to reproduce, evaluation energy win/lose: 40/–40, passed from the loser to the winner, death energy level: 0, used to decide which agent should be removed from the system, boundary condition for the intra-island lattice: fixed, the agents cannot cross the borders, intra-island neighborhood: Moore's, each agent's neighborhood consists of 8 surrounding cells, size of 2-dimensional lattice as an environment: 10×10, all agents that decided to emigrate from one island, will immigrate to another island together (the same for all of them).

The local search in memetic versions was isotropic mutation – it is a method aimed at generating uniform sampling points on and within N-dimensional hyper-spheres. The idea of the Isotropic method algorithm is as follows: firstly, the N normal distributed numbers z_i are generated. Then the vectors x are computed by making a projection onto surface by dividing each generated number z_i by $r = \sqrt{\sum_{i=1}^{N} z_i^2}$. Since the z vectors are isotropically distributed, the vectors x will be of norm 1 and also isotropically distributed. Therefore the points will be distributed uniform of the hypersphere. The generation of points inside the hypersphere may be achieved by rescaling the coordinates obtained in the previous steps. While rescaling, the dimension must be taken into consideration [22]. Such a mutation was performed in 10 phases, in each of the phase 10 mutations were made and the best result was passed to the next phase.

The detailed results obtained in the course of the experiments are presented in Figs. 3 and 4. It is easy to see that for the considered problem, EMAS obtained better results for all its memetic versions while maintaining stable population of agents. What is more the diversity measures clearly indicate, that this feature is significantly better in EMAS, at least in the beginning of computation, so the exploration phase is apparently longer. Relatively high dispersion of the results calls for detailed analysis of the problem stated, and possibly to employ more sophisticated methods (e.g., niching, [23]), in order to reach and clearly report more than only one extrema of the optimized problem.

Besides visual assessment of the obtained results, an insight into attained solutions is of course necessary. In Table 1

Table 1
Final results obtained by the researched systems

System	Fitness	Standard deviation
PEA	75.6	35.51
PEA + Baldwin	93.6	68.91
PEA + Lamarck	77.4	13.82
EMAS	**37.2**	**0.4**
EMAS + Baldwin	47	59.39
EMAS + Lamarck	80.4	33.83

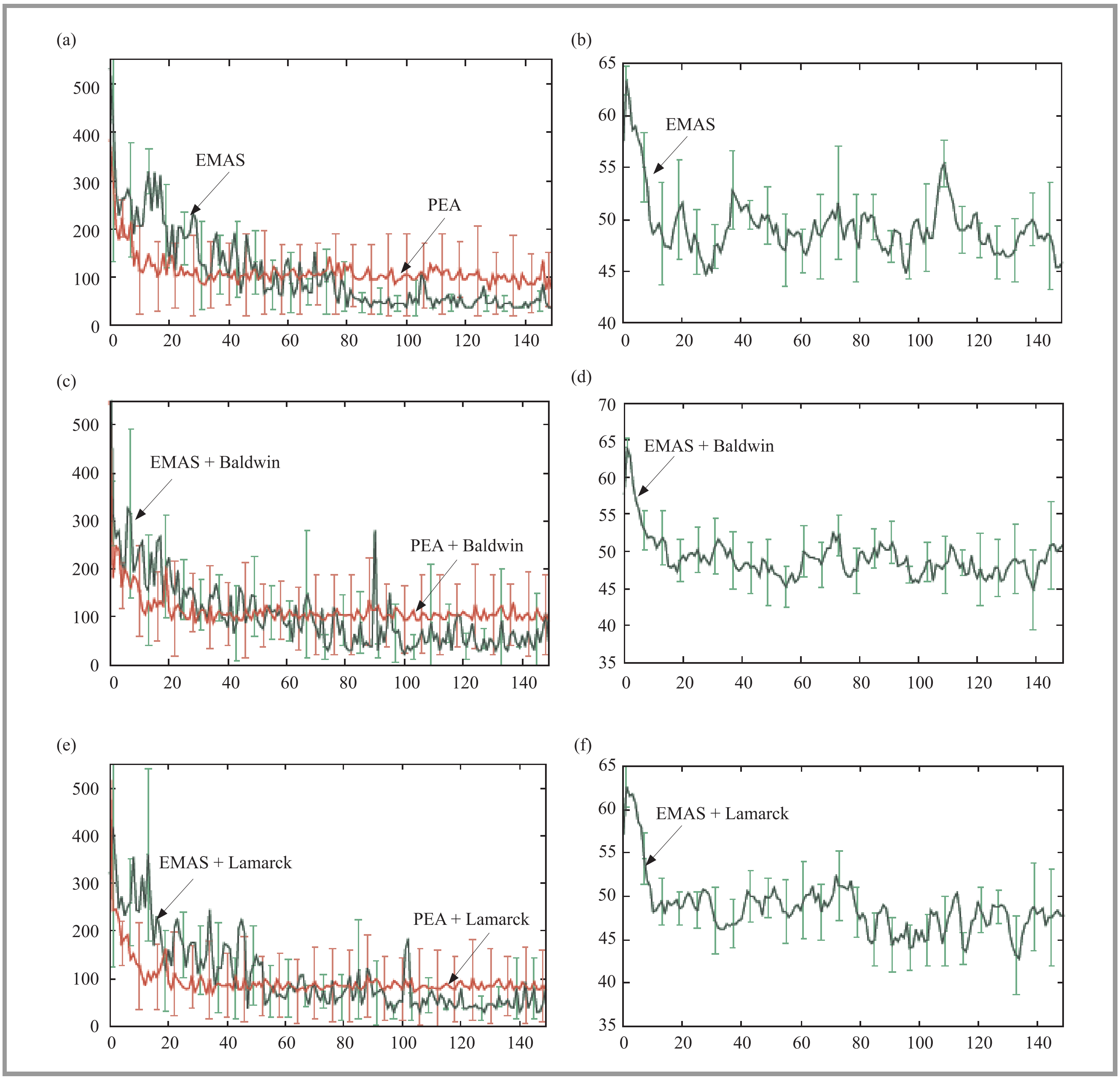

Fig. 3. Fitness and agent count obtained for all tested systems: (a) EMAS and PEA fitness, (b) EMAS agent count, (c) EMAS and PEA (Baldwin) fitness, (d) EMAS + Baldwin agent count, (e) EMAS and PEA (Lamarck) fitness, (f) EMAS + Lamarck agent count.

the obtained fitness value in the last (150th) step of the computation was presented. It is to note, that the best result has been reached by EMAS without modifications. The next one was apparently EMAS with Baldwinian memetics, unfortunately high dispersion of this results point out that it should be disqualified. In the case of Lamarckian memetics, the final result obtained is worse than in the case of PEA.

5. Conclusions

In the paper an agent-based approach to parametric optimization of advisory strategy was presented. As a case study, decision support strategy in Sudoku solving was considered. The problem of optimization of these parameters was defined based on an originally proposed decision support method, constructed and inspired by the most common way of solving this puzzle by human.

However, the main stress is put on applying the agent-based optimization metaheuristics to the above-stated problem. Here, Evolutionary Multi-agent System and its memetic modifications were considered and compared to classical Parallel Evolutionary Algorithm. The results obtained by EMAS turned out to be better than these obtained by PEA. One exception was Lamarckian memetic operator, as in this case PEA turned out to be better, but both results were in

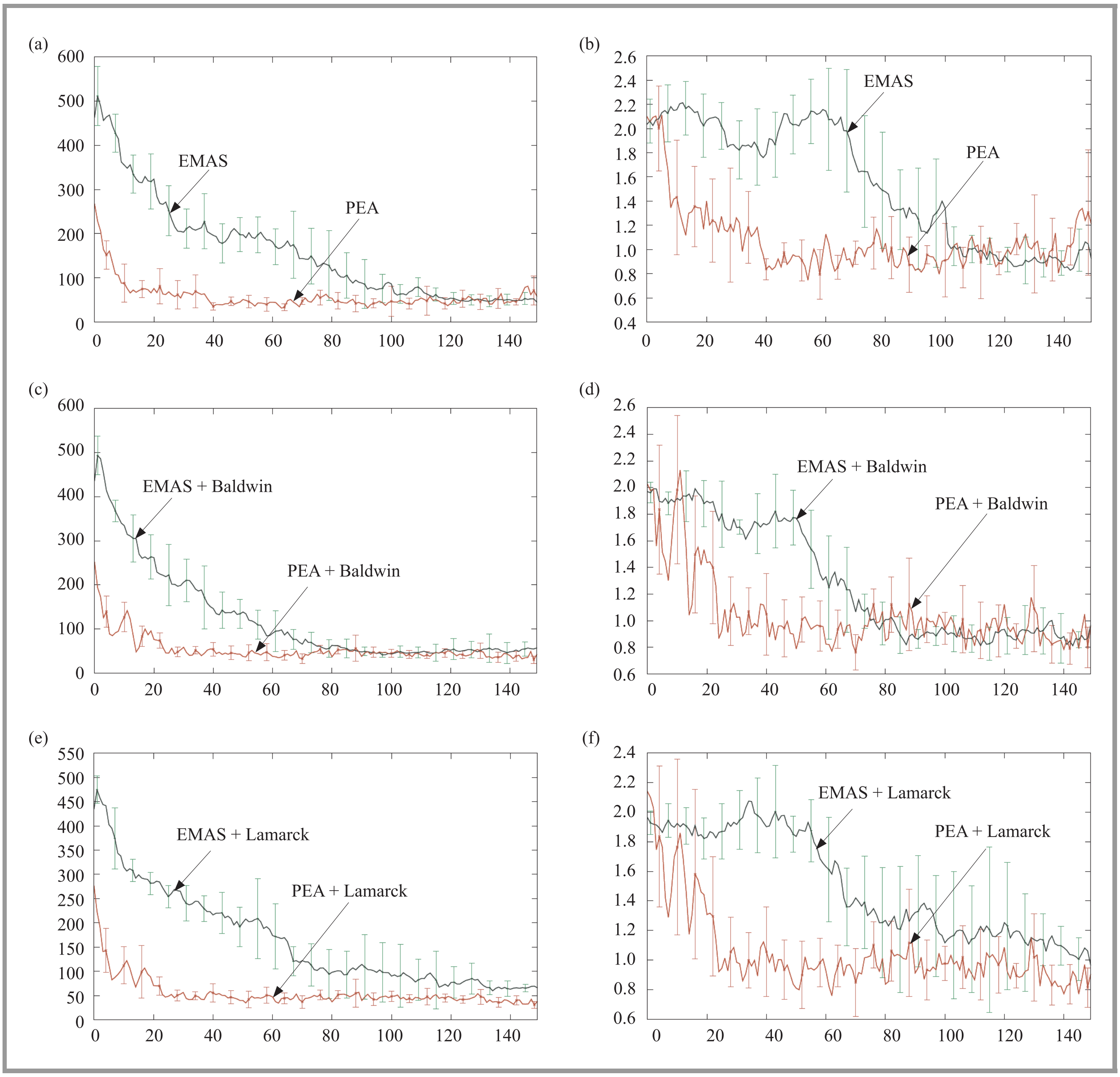

Fig. 4. Diversity obtained for all tested systems: (a) EMAS and PEA MSD diversity, (b) EMAS and PEA MOI diversity, (c) EMAS and PEA (Baldwin) MSD diversity, (d) EMAS and PEA (Baldwin) MOI diversity, (e) EMAS and PEA (Lamarck) MSD diversity, (f) EMAS and PEA (Lamarck) MOI diversity.

the same range and the dispersion measure did not allow to clearly choose the one better than another.

The obtained results support the already verified in other problems observation, that agent-based computing tends out to be better than classical algorithms. However, it should be noted that the standard deviation of the obtained outcomes is quite high, so therefore, putting an additional effort is required to cause higher repeatability of the experiments.

In the future, incorporation of the mentioned Sudoku solving strategies into the proposed method is envisaged. Tackling other difficult problems with EMAS and related approaches is also planned.

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