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Alessandro Bogliolo, Università di Urbino, Italy

ACCESS 2013

Foreword

The Fourth International Conference on Access Networks (ACCESS 2013), held between July 21 and July 26, 2013 in Nice, France, continued a series of conferences dealing with access networks, services and technologies based on the previous NEUTRAL and HOWAN workshop treating particular access aspects. ACCESS 2012 aimed to provide an international forum by researchers, students, and professionals to present recent research results on advances in networking access.

We take here the opportunity to warmly thank all the members of the ACCESS 2013 Technical Program Committee, as well as all of the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to ACCESS 2013. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the ACCESS 2013 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that ACCESS 2013 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of access networks.

We are convinced that the participants found the event useful and communications very open. We hope that Nice, France provided a pleasant environment during the conference and everyone saved some time to enjoy the charm of this city.

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Minimizing the Power by using Genetic Algorithms for Multi-User OFDM Systems

Ndiaye Abdourahmane, Ouya Samuel, Mendy Gervais and Farssi S. Mohamed
Ecole Supérieure Polytechnique de Dakar
Université Cheikh Anta DIOP de Dakar
Dakar, Senegal
Email: rahabdou2003@yahoo.fr, samuel.ouya@gmail.com, gervaismendy@ucad.edu.sn, farsism@yahoo.com

***Abstract*—This paper considers the problem of minimizing power consumption of the base station in the downlink of the multi-user OFDM cellular network, characterized by frequency selective transmission channel. The channel gain is variable and specific for each user. In this case, the resources allocation must be determined so that the total power consumption is as low as possible. To solve this problem, we proposed an implementation ofsome genetic algorithms and we obtained a better solution than currently applied well-known methods.**

Keywords*—*OFDM; Genetic Algorithms; Multi-User; Frequency Selectivity; Resources Allocation

I. Introduction

The second and third generation of cellular network are characterized by single carrier transmission. For each user, one subcarrier is used during the communication that often causes lost of signal in the context of channel frequency selective. However, in 4G cellular systems [13], the multi-carrier transmission's technique OFDM (Orthogonal Frequency Division Multiplexing) [24] is used in order to fight against multipath phenomena and to provide a significant throughput to users. In the OFDM transmission technique, the total available bandwidth is split into many narrow bands subchannels at equidistant frequencies [21]. Each subchannel has approximately a constant channel gain and the bit loading can be adjusted according to the level of the channel gain.

The orthogonality of the subcarriers permits to reduce the width of the transmission subchannels; thereby, increases the spectral efficiency. The high number of the subcarriers makes possible to perform a more effective management, by adapting the subcarriers allocation according to the channel gain of the users [22].

In the context of frequency selective channel, where the channel gain is variable and specific for each user, the optimal resources allocation is an optimization problem. The adaptive resources allocation is a proposed method to improve the performance of cellular systems. The adaptive allocation can give 20dB of Signal-to-Noise-Ration in contrast to random allocation [2].

In multi-users OFDM cellular systems, the resources allocation consists in solving an optimization problem with constraint. It takes the channel estimated characteristics. In practice, the channel gain is given by receiver in logic channel CQIH (Channel Quality Indicator Channel) [8]. Note that, this optimization problem is highly nonlinear; therefore, it is unlikely that the algorithm with polynomial complexity be used [15].

Thus, several algorithms are developed for solving the resources allocation problem. The water-filling algorithm proposed by Tu et al. [23] proved to be optimal for solving the power-minimizing problem in the single-user case. Improvements have been introduced by Qi et al. [3], and Munz et al. [6], in order to reduce complexity of the water-filling algorithm. The Greedy algorithm proved to be optimal to solve the bit loading algorithm in single-user case [12]. However, the problem of resources allocation becomes very complex in multi-user OFDM systems. Wong et al. [4] proposed a suboptimal method to allocate subcarriers, but the method requires iterative process and the foreknown required number of subcarriers allocated to users [9]. Kim et al. [14] converted the non-linear optimization problem into a linear one with integer variables. The optimal solution can be achieved by integer programming (IP), but its computation is still very huge [9].

In this context, the evolutionary approach inspired by natural phenomena are introduced to improve the resources allocation [7]. Among this methods, we propose in this paper to solve the optimization problem with GAs (Genetic Algorithms). The main objective of this work is to propose an implementation of some GAs in order to have better results.

In Section 2, the related work about resources allocation is described. In Section 3, the modeling system and the formulation of the optimization problem are presented. In Section 4, the principle of genetic algorithms is given and in Section 5, the proposed algorithm is described. Finally, in Section 6, we compare the results of the proposed algorithm to others algorithms.

II. Related work

Genetic algorithms belong to the family of evolutionary algorithms inspired by biology. It is first introduced by H. Holand [11] and implemented by D. Goldberg [7] for solving optimization problems. Since the GAs is an effective search technique, it has been applied to wireless communications recently [1][5][20][17].

Most of the work based on the genetic algorithms use the same procedure. However, the difference lies in the implementation and the method of GAs's operators. In the work proposed by Zhu et al. [18], the natural selection's method is used, while it accelerates the algorithm but not ensure converging towards the global optimum [16]. In this paper, we used the method of selection by tournament, that keeps diversity of the population during the process and allows a better exploration of the search domain [10].

In many proposed implementation, the constraint of the optimization problem is considered in the evaluation of the fitness (objective function) of individual. This can deplete the population and limits the exploration of the search domain. In our proposed implementation, the fitness is only based on the power according to equation (4). To meet the constraints of the optimization problem, we defined the function named $adjust\_allocation$ so as to balance the throughput of users.

III. System modeling and Formulation of the problem

A. System modeling

We consider an OFDM multiple access system, in which the characteristics of transmission channel are assumed known by the transmitter and the receiver. The channel is assumed to be linear and stationary, with additive white gaussian noise of zero mean. It is decomposed into N flat subchannels and each of which is characterized by a constant gain, specific for the nth subcarrier and the kth user.

The transmission channel is frequency selective, and we assume that the users are in micro-mobility; therefore, the Doppler effect is ignored. We note that, there are no inter-symbol interferences, since subcarrier is allocated to a single user. We consider the mono cellular system. The number of users and subcarriers is constant during the GAs process.

B. Formulation of the problem

The channel of transmission is frequency selective. It can be considered as a filter, characterized by the transfer function varying with frequencies and of each user. The magnitude of the transfer function corresponds to the gain of the transmission channel.

Let $H_{k,n}$ the channel gain of the kth user on the nth subcarrier. The required power is given by Proakis [19]:

$$p_{k,n} = \frac{f(c_{k,n})}{H^2_{k,n}} \tag{1}$$

where

$$f(c_{k,n}) = \frac{N_0}{3}(2^{c_{k,n}} - 1)[Q^{-1}(\frac{BER_k}{4})]^2 \tag{2}$$

$c_{k,n}$ is the number of bits for the kth user on the nth subcarrier. N_0 is the power spectral density of the noise. BER_k is the bits error rate of the kth user. $Q(x) = erfc(x)$ is the complementary error function.

Note that, when the channel gain $H_{k,n}$ increases, the power required decreases. Thus, the nth subcarrier will be allocated in preference to the kth user having the smallest power to achieve the required throughput. As the number of subcarriers is high, it is not necessary that many users share the same subcarrier (Time Division Mutliplexing). In addition, the inter-symbol interferences can be avoided when one subcarrier is exclusively allocated to one user.

Let $\rho_{k,n}$ the allocation factor of the nth subcarrier to the kth user defined by:

$$\rho_{k,n} = \begin{cases} 1 & \text{if the } nth \text{ subcarrier is allocated to the } kth \text{ user} \\ 0 & \text{else} \end{cases} \tag{3}$$

The total power allocated to the kth user is given by:

$$P_k = \sum_{n=1}^{N} p_{k,n}.\rho_{k,n} = \sum_{n=1}^{N} \frac{f(c_{k,n})}{H^2_{k,n}}.\rho_{k,n} \tag{4}$$

Thus, the total power allocated to all users is given by:

$$P_T = \sum_{k=1}^{K} P_k = \sum_{k=1}^{K}\sum_{n=1}^{N} \frac{f(c_{k,n})}{H^2_{k,n}}.\rho_{k,n} \tag{5}$$

The total bits for the kth user is given by:

$$r_k = \sum_{n=1}^{N} c_{k,n}.\rho_{k,n} \tag{6}$$

The equation (1) shows that the required power for the kth user on the nth subcarrier is inversely proportional to the channel gain $H_{k,n}$. Therefore, it is more efficience to allocate the nth subcarrier to the kth user which presents the smallest channel gain $H_{k,n}$. Thereby, the power can be minimized while the constraints of QoS are satisfied.

Thus, the problem of resources allocation can be written:

$$min(P_T)$$

subject to

$$r_k > r_0$$

where r_0 is the minimal rate for the kth user.

IV. Genetic Algorithms

Genetic algorithms are inspired by Darwin's theory of evolution and by Mendel's works about recombination of species [16]. GAs are used to solve many problems of optimization.

Robustness is the main advantage of genetic algorithms relative to traditional resolution methods of optimization problems [7]. In other words, we can see the four major differences between the two methods:

1) GAs work with a coding of the set of parameters, while the classical methods use directly the parameters.
2) The solution given by GAs is a set of points (chromosomes) and the solution for a classical methods is a single point.
3) GAs use the objective function and the standards methods often use derivatives of function or other auxiliary knowledge.
4) Gas use probabilistic transition rules when the traditional methods use deterministic rules.

The principle of GAs is based on the evolution of an initial population under the effect of operators such as selection, mutation and crossover. At the end of the GAs's process, the best individual in the population will be the solution of the optimization problem.

The different phases of the GAs are:

- Coding of chromosome
  A chromosome of the population represents a resource allocation scheme. The coding of the chromosome is to provide a structure corresponding to the resource allocation problem. In our implementation, chromosome is represented by an array of structure, containing a fixed number of subcarriers, numbered in increasing order, from 0 to $N-1$. In the nth cell, there are the index of the user to which the corresponding subcarrier is allocated. The required power and the quantity of bits are calculated from this allocation for every user. All chromosomes have the same fixed size which corresponds to the total number of subcarriers. The following table shows an example of the structure of the chromosomes .

TABLE I. STRUCTURE OF CHROMOSOME

Subcarrier	1	2	- - -	N
User	5	3	- - -	10

- Initialization of the population
  It consists to set the size of the population and to generate all chromosomes of the population. In this work, the chromosomes of the population are randomly generated and their size is the same and stays constant during the GAs process.
- Evaluation
  In this function, the total required power and the total throughput are calculated for each chromosome. The required power corresponds to a fitness (objective function) of the chromosome. The fitness or the objective function represents the criterion of the selection of chromosomes.
- Selection
  After evaluating the power of all chromosomes, the selection consists to retain the best chromosome by directly sorting (natural selection) or by organizing tournament between two chromosomes arbitrary selected (selection by tournament). The best chromosome of the population is the one that the requires power is the smallest while respecting the constraint of throughput.
- Mutation
  It consists to bring changes to the resources allocation scheme in order to have a better exploration of the search domain. In this work, the number of mutations and the index of the mutated subcarrier are randomly determined for each chromosome. Note that, all chromosomes will not be affected by the mutation.
- Crossover
  In this step, a new chromosome is created from two chromosomes in order to take advantages of their best characters. Two points of crossover are randomly chosen and two parts of the first chromosome are concatenated with one part of the second chromosome. So, a new chromosome is created from this concatenation.

V. DESCRIPTION OF THE PROPOSED ALGORITHM

input:
$N_{Carrier}$: number of subcarriers
N_{User}: number of users
$Size_{pop}$: size of the poplutation
$Ngen$:number of generation of the GAs process
Step 1: Coding of chromosome
$Structure\ subcarrier\{$
$user$
$power$
bit
$\}$
$chrom[N_{Carrier}]$ //vector of subcarriers
Step 2: Initialization population
$for\ t\ =\ 1\ to\ Size_{pop}$
$for\ n\ =\ 0\ to\ N_{Carrier}-1$
$\{$
$k \leftarrow rand(N_User)$
$chrom[t].user \leftarrow k$
$chrom[t].bit \leftarrow c[k][n]$
$chrom[t].power \leftarrow f(c[k][n], H[k][n])$ // According to equation 1.
$\}$ **Step 3: Evaluation chromosome**
$for\ i\ =\ 1\ to\ Size_{pop}$
$\{$
$P_{chrom}(i) \leftarrow 0$ // Initialization the power of the chromosome
$for\ n\ =\ 0\ to\ N_{Carrier}-1$
$\{$
$P_{chrom}(i) \leftarrow\ P_{chrom}(i)\ +\ chrom[n].power$
$\}$
$\}$
Step 4: Selection by tournament
$c_1 \leftarrow rand(Size_{pop})$
$c_2 \leftarrow rand(Size_{pop})$
$p_1 \leftarrow P_{chrom}(c_1)$
$p_2 \leftarrow P_{chrom}(c_2)$
$if\ p_1\ <\ p_2\ then$ // chrom c1 better than chrom c2
$population\_next\_generation \leftarrow chrom[c_1]$
$else$ // chrom c2 better than chrom c1
$population\_next\_generation \leftarrow chrom[c_2]$
Step 5: Mutation
$n_{chrom} \leftarrow rand(Size_{pop})$ // number of chromosome to mutate
$for\ i\ =\ 0\ to\ n_{chrom}$
$\{$
$c_1 \leftarrow rand(Size_{pop})$ // chromosome's index
$n_{mutation} \leftarrow rand(Size_{pop}/8)$ // number of mutation
$for\ j\ =\ 1\ to\ n_{mutation}$
$\{$
$n \leftarrow rand(N_{Carrier})$
$chrom[i].user \leftarrow rand(N_{User})$ // changes of user allocation
$\}$
Step 6: Crossover
$c_1 \leftarrow rand(Size_{pop})$
$c_2 \leftarrow rand(Size_{pop})$
$pc_1 \leftarrow rand(N_{Carrier})$ // first crossover point
$pc_2 \leftarrow rand(N_{Carrier})$ // second crossover point
$offspring \leftarrow concatenate(chrom[c_1], chrom[c_2], pc_1, pc_2)$
Step 4 to **6** are repeated until the number of generation Ngen is reached
Step 7: Search best chromosome

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$best\_chrom \leftarrow 1$
$for\ k\ =\ 2\ to\ Size_{pop}$
$\{$
$if\ P_{chrom}(k)\ >\ P_{chrom}(best\_chrom)$
$best\_chrom \leftarrow k$
$\}$

Step 8: Adjust allocation

In this step, the best allocation scheme resulting from the GAs process, is adjusted in order to achieve the throughput constraint. In this paper, the throughput constraint is not considered in the calculation of the objective function. Here, the proposed solution of the genetic algorihms is only based on the criterion of the power and requires to be eventually adjusted.

VI. SIMULATION

A. Parameters simulation

- BER (Bit Error Rate): 10^{-2} to 10^{-4}
- M-QAM: M in $\{4, 8, 16, 32, 64\}$ M is the parameter of the modulation QAM (Quadrature Amplitude Modulation). It corresponds to the number of symbols of the modulation. M equal to 2^n where n is the number of bits per symbol.
- Power spectral density of the noise: $N_0 = 0.01$
- Number of subcarriers: 128
- Size of the population: 200
- Symbols rate: $14kbauds$ (3GPP Standard)
- Minimal user's rate: $r_0 = 750kbits/s$. It is calculated according to the number of subcarriers and the number of users.

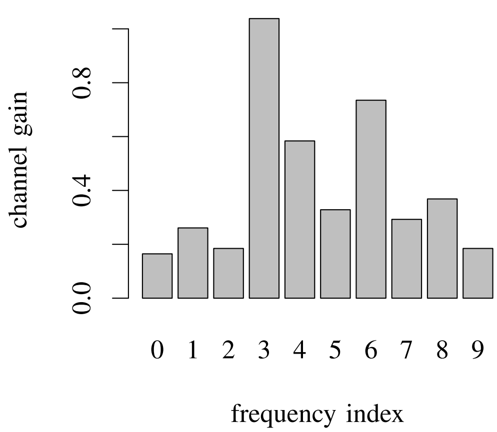

Figure 1. Variation of channel gain of one user

B. Results of simulation

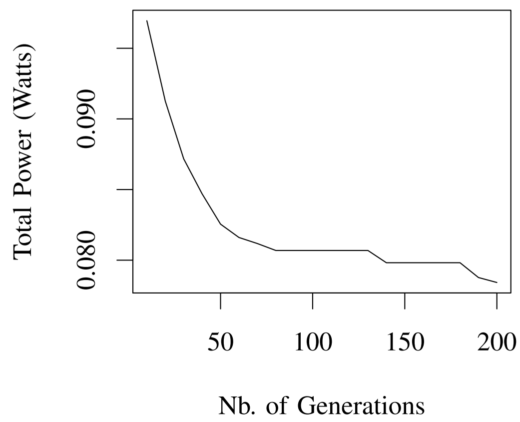

Figure 2. Convergence of our algorithm with 8 users, 128 subcarriers and $N_0 = 0.0001$.

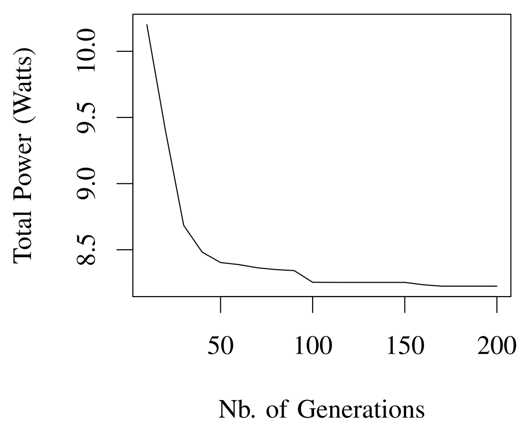

Figure 3. Convergence of our algorithm with 8 users, 128 subcarriers and $N_0 = 0.01$.

Figure 4. Variation of total power with different size of the population with 8 users, 128 subcarriers and $N_0 = 0.01$.

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TABLE II. COMPARISON OF OUR ALGORITHM AND THE ALGORITHM PROPOSED BY AHMADI ET AL. [1] WITH $N_0 = 0.0001$

	2 users	4 users	8 users
Our algorithm	0.01w	0.022w	0.061w
Ahmadi and Chew	0.03 w	0.05 w	0.12 w

TABLE III. COMPARISON OF OUR ALGORITHM AND THE ALGORITHM PROPOSED BY REDDY ET AL. [20] WITH $N_0 = 0.01$

	2 users	4 users	6 users	8 users
Our algorithm	0.98 w	2.09 w	3.77 w	5.68 w
GaReddy	5w	8 w	12w	15w

C. Analysis of results

The study of the evolution of the power, according to the number of generations (Figure 2), shows that the power remains relatively constant from the $80th$ generation and the corresponding resources allocation scheme is the solution of the optimization. Figure 4 shows some problems of convergence of the proposed algorithm; however, the total power decreases when the size of population increases. We also note that the result is better with large population size. The GAs that we implemented, gives better results than baseline algorithms met in the literature. The Tables II and III above, compare the consumption of the power for different numbers of users of the algorithm proposed in this work to the algorithms developed by Ahmadi et al. [1] and by Reddy et al. [20].

VII. CONCLUSION AND FUTURE WORK

In this paper, we have implemented the genetic algorithms to solve the problem of resources allocation in a frequency selective transmission channel. The implementation of the GAs that we proposed is characterized by the function named $adjusted\_allocation$ which permits to balance the resources allocation scheme of the obtained solution. The implementation of the proposed GAs in this paper gives better result than the algorithm proposed by Ahmadi et al. [1] and the algorithm proposed by Reddy et al. [20]. We have implemented the proposed GAs in this paper in C language, which gives us a good modeling. We hope that the execution of our model will be faster than others tools as Matlab or Scilab. In future works, we will try to improve the convergence of the proposed GAs.

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Impact of Voice Payload Size on Behaviour of the Field Network of the Armed Forces of the Czech Republic

Zuzana Vranova, Antonin Mazalek
Faculty of Military Technology
University of Defence
Brno, Czech Republic
zuzana.vranova@unob.cz; antonin.mazalek@unob.cz

***Abstract* - This article deals with a choice of voice payload size and its impact on the behavior of the field network of the Armed Forces of the Czech Republic. The contradictory requirements for a high throughput and at the same time a high quality of transmitted voice are discussed. First, a theoretical analysis of the problem is carried out. The theoretical assumptions were compared with those obtained in experiments in laboratory conditions. The result of the experiments is to determine the optimal size of the voice payload size with regard to the specific characteristics and requirements on the battlefield. According to the results we can recommend an optimal voice payload size with respect to the G.114 Recommendation. Thus up to 80 % of bandwidth saving will be achieved.**

Keywords – VoIP; voice payload size; network bandwidth; battlefield

I. INTRODUCTION

The Army of the Czech Republic has recently completed modernization of communication infrastructure of the field network. According to current trends in the world communications, the backbone of battlefield is based on the transmission of information using the IP protocol, published by Postel [1]. After overcoming primary difficulties, the modernization brought a stable network enabling the use of a number of new advanced services. A major benefit of the field network modernization with regard to its specific character is a possibility of an easy and secure encryption of a data and voice traffic. The basic building components of the backbone are Cisco 2800 and 3800 series routers that use the services of Cisco CallManager Express (CCME) [2] for the providing of voice services on the VoIP principles. Particular communication nodes are connected by radiorelay links realizing the E1 interface [3].

With today's technical possibilities of digitized battlefield, a bigger focus is getting on the network bandwidth. In addition, a number of applications require a real-time operation. With regard to this trend, the E1 interface with a capacity of 2 Mb/s represents a weak point of the network. Therefore, it is necessary to find a solution to make the transmission of the required information more efficient.

There are many possibilities on how to solve the problem always with regard to the specifics of the analyzed network. Choudhury and Gibson [4] deal with the issue of effectiveness of multimedia transport in wireless access networks. Specifically, the work deals with the possibility of optimizing the efficiency of transmission, depending on the choice of transmission rate and payload length in IEEE 802.11 network. Bhanu, Chandrasekaran, and Balakrishnan [5] solve security of the required quality of services in VoIP 802.11 environment. A Bandwidth Data rate Moderation (BDM) algorithm has been proposed which correlates the data rate specified in IEEE 802.11b with the free bandwidth. Payload size is one of the input parameters of the BDM algorithm. The way to make the data transfer at a tactical command level more efficient by a header compression technique is addressed in the article of Yoon, Park, Lee, Kim, and Jee [6]. Nowadays, modern VoIP networks place attention to safety issues and therefore the voice encryption. Epiphaniou [7] addresses among others the influence of the used encryption and voice payload size on the delay and packet loss. All considered changes need to be addressed with regard to the required voice quality. For example, the voice quality expressed in Mean Opinion Score (MOS) in dependence on voice payload size and packet loss is engaged in the publication of Becvar, Vondra, and Novak [8].

Unlike those publications, we examine specific real network with sufficiently dimensioned HardWare (HW) because of increased requirements on network reliability. We need not, therefore, deal with the impact of packet loss on speech quality. In addition, the network uses external encryption equipment with sufficient packet throughput. These facts allow us to simplify the initial conditions for the experiments.

The weak point of the analyzed network are the radiorelay links realizing the E1 interface. So, the main goal of our work is to optimize efficiency of transmission of VoIP data on E1 links. Furthermore, we use the fact that the E1 interface uses specific data link layer protocols different from the protocols considered in the above publications.

The organization of this paper is as follows. In Section 2, we present factors affecting the level of savings in bandwidth. In Section 3, there is explained a principle of bandwidth calculation for one call in VoIP environment when voice payload size is explored. In Section 4, results of voice payload size optimization in battlefield conditions are shown. In Section 5, we outline our conclusions and we mention our future work.

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II. FACTORS AFFECTING THE LEVEL OF SAVINGS IN BANDWIDTH

Nowadays, there are many views how to optimally solve existence of two contradictory requirements on the most efficient use of bandwidth on one hand, and, on the other hand, provision of the high quality voice in the VoIP environment. The rule is that a codec type significantly affects the quality of provided services and the required bandwidth. Its parameters, such as a codec sample interval (CSI), a codec sample size (CSS), are given the same as a value of Mean Opinion Score (MOS) for the default type of codec. Based on the codec, CSI is a sample interval at which the codec operates and CSS is the number of bytes captured by the Digital Signal Processor (DSP) at each codec sample interval. From these two parameters, we can derive another parameter. It is a codec bit rate (CBR) (1)

$$CBR = CSS / CSI \ \text{[b/s]}. \quad (1)$$

MOS is a result of subjective or objective methods of speech quality assessment as Bestak, Vranova, and Ondryhal refer [9]. Its values and interpretation are shown in Table 1.

TABLE I. MOS SPEECH QUALITY CLASSIFICATION

MOS	Quality	Note
5	Excellent	Excellent speech quality
4	Good	Quality comparable to analogue phone networks
3	Fair	Fair speech quality
2	Poor	Poor speech quality
1	Bad	Unintelligiblecall

If we use two of the most common codec types, thus G.711 and G.729 codecs, the MOS can reach values up to 4.1 and 3.9.

Note: Due to complexity of nowadays networks, the MOS parameter is no longer sufficient and has been replaced by R-factor, which is more suitable for IP networks. The R-factor is the output of the E-model (according to ITU-T G.107).

In the next step, it is needed to consider a possibility of application of header compression mechanisms or Voice Activity Detection (VAD) techniques. Header compression is possible only when the point-to-point communication occurs. By default, the use of the efficient compression of IP/UDP/RTP headers is used according to Casner and Jacobson in RFC 2508 [10] and Bormann, et al. in RFC 3095 [11]. It reduces the headers up to 2 or 4 bytes. It is not suitable to use this mechanism directly over the Ethernet. However, we can use encapsulation using a Point-to-Point Protocol (PPP) according to Simpson [12]. PPP provides standard services for transmission of different formats of datagrams through serial lines (RFC 1661). PPP is one of the Layer 2 protocols which can also compress the headers in some cases.

VAD is a mechanism that certainly saves bandwidth. However at the same time, it places greater demands on implementation in the terminal equipment. In many cases, the active VAD can result in losses of beginnings of call segments, which greatly decrease quality of voice services. For more complex services, the VAD implementation can even bring errors and cause problems with operation of more complex services. We had such specific experience when we deployed faxes in the field VoIP network.

Another factor that must be considered when optimizing the size of the payload is loading of a router. A large number of short packets are right for real-time applications with respect to small delay but it increases an overhead and computational demands imposed on the routers. A large number of shorter packets and necessity of their processing in nodes paradoxically leads gradually to an increase of the total delay in transmission, in the next step to packet losses and thus to further deterioration of the voice quality and to the flooding of the nodes and a link failure.

Other parameters describing transmission conditions in the particular VoIP network are Voice Payload Size (VPS) (By), Voice Payload Interval (VPI) (ms) and Packets Per Seconds (PPS). The voice payload size represents the number of bytes (or bits) that are filled into a packet. The voice payload size must be a multiple of the codec sample size. The voice payload interval is processed length of a voice segment inserted into one sent packet. PPS represents the number of packets that need to be transmitted every second in order to deliver the codec bit rate. Just these parameters can be varied to optimize network throughput and the voice quality, respectively to look for the best compromise with regard to specifics of the analysed network.

With regard to the facts mentioned above, there can be defined initial conditions for optimization of transfer characteristics of the analysed field network as follows: the mechanism of headers compression is not used, VAD is set, the G.729 codec is used. A computing power of routers with regard to the adequate field network dimensioning is not discussed. A weak point of the field network is the E1 lines. Of possible solutions, we focus on the influence of payload size on the behaviour of the analysed network in our work. We will examine effectiveness of transfer on Layer 3 with respect to the payload size. For now, we will not consider the influence of Layer 2 to which is applied the High Level Data Link Control (HDLC) protocol. Whether the results are relevant even after consideration of the characteristics of HDLC protocol will be verified in the next part of the project.

A. *Characteristics of the G.729codec*

The G.729 codecs are often deployed in VoIP networks in order to save the bandwidth. For example, Cisco technology uses them as a default set in the outgoing direction from the network. In order to save the bandwidth, the G.729 codec is also used as a default set in the analysed army field network.

The G.729 codec is specified in ITU-T Recommendation G.729 [13]. Coding of speech is at 8 kbit/s using Conjugate Structure – Algebraic Code Excited Linear Prediction (CS-ACELP). A reduced – complex vision of the G.729 algorithm is specified in Annex A to Rec. G.729. The speech coding algorithms in the main body of G.729 and in G.729 Annex A are fully interoperable with each other. An implementation that signals or accepts use of the G.729 payload format may implement either G.729 or G.729A. The G.729 and G.729 Annex A codecs were optimized to represent speech with high quality where G.729 Annex A transmits some speech quality for an approximate 50% complexity reduction. For all data rates, the sampling frequency (and RTP timestamp clock rate) is 8000 Hz. The Voice Activity Detector (VAD) and the Comfort Noise Generator (CNG) algorithm in Annex B of G.729 are recommended for digital simultaneous voice and data application. An example of G.729 and G.729A bit packing according to ITU-T Recommendation G.729 is in Figure 1.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|      L1     |    L2   |    L3   |       P1      |P|    C1   |
|0|             |         |         |               |0|         |
| |0 1 2 3 4 5 6|0 1 2 3 4|0 1 2 3 4|0 1 2 3 4 5 6 7| |0 1 2 3 4|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       C1      |  S1   | GA1 |  GB1  |    P2   |      C2       |
|          1 1 1|       |     |       |         |               |
|5 6 7 8 9 0 1 2|0 1 2 3|0 1 2|0 1 2 3|0 1 2 3 4|0 1 2 3 4 5 6 7|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   C2    |  S2   | GA2 |  GB2  |
|    1 1 1|       |     |       |
|8 9 0 1 2|0 1 2 3|0 1 2|0 1 2 3|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1. Example of G.729 and G.729A bit packing.

The transmitted parameters of a G.729/G.729A are 10 ms frame, consisting of 80 bits. The mapping of these parameters is given on the Figure 1. The bits of each 32-bit word are numbered from 0 to 31, with the most significant bit on the left and numbered 0. The octets (bytes) of each word are transmitted with the most significant octet first.

III. Calculation of One Call Bandwidth in VoIP Environment

In theoretical calculations of bandwidth required for one call, it is necessary to know particular operating technology, including protocols employed in each level of the communication model.

Bandwidth calculation formulas in general [14]:

$$TPS = L2H + OH + VPS \ \ [\mathrm{By}], \tag{2}$$

$$PPS = CBR / VPS \ \ [1/\mathrm{s}], \tag{3}$$

$$Bandwidth = TPS * PPS \ \ [\mathrm{b/s}], \tag{4}$$

where: L2H is Layer 2 header
TPS is Total Packet Size
OH is overhead of IP/UDP/RTP headers.

Since different systems differ in Layer 2 protocols the most frequently, an operational efficiency is evaluated at Layer 3. Here, we are dealing with overhead of IP/UDP/RTP headers. Layer 2 has often a major impact on the efficiency of transmission. We considered the effect of Layer 2 in the previous work [15], when we analysed the effect of network load on the voice quality. We interconnected two LAN networks using 2811 Cisco routers. The routers were connected through the Catalyst 2950 Switch via Ethernet in a mode of full duplex at 10 Mb/s. This link represents a critical point of the network because of its slow speed. We calculated the theoretical value of how many simultaneous calls can be transferred over a tested line, so we needed to know the bandwidth required for one call.

In this case, we used (see Figure 2):

- G.711 codec
- Sampling frequency = 8000 Hz
- VPI = 30 ms
- VPS = 240 By
- Layer 3 headers = IP header 20 By + UDP header 8 By + RTP header 12 By = 40By
- Layer 2 (Ethernet) header = 38 By (8 By of preamble, 14 By of the source and destination MAC addresses and the length, 4 By of CRC, 12 By of interframe gap).

Note: Possibility of VAD usage and header compression is not considered.

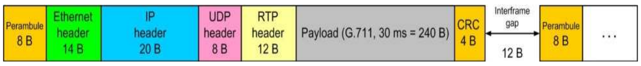

Figure 2. Necessary overhead for transmissionof one 30 ms voice segment.

According to (2), (3) and (4), we need bandwidth for transmission of one voice channel:

TPS = (38 + 40 + 240) = 318 By,

PPS = 64000 / 240 * 8 = 33.333 1/s,

One call bandwidth = 318 * 8 * 33.333 = 84800 b/s.

We get interesting results to the effectiveness of bandwidth usage when using the G.729 codec and the same VPI = 30 ms, so VPS = 30 By:

TPS = (38 + 40 + 30) = 108 By,

PPS = 8000 / 30 * 8 = 33.333 1/s,

One call bandwidth = 108 * 8 * 33.333 = 28800 b/s.

Thus by changing of the codec type will be saved about 2/3 of the bandwidth with slight deterioration of the voice quality (measured by MOS or R - Factor).

IV. Results of Voice Payload Size Optimization in Field Network Conditions

In the previous section, we set the initial conditions for the theoretical part and following experiments. Relations (2-4) allowing calculation of required bandwidth for a single call at Layer 3 are the starting point. VPS is one of variable parameters. Cisco routers allow setting of different values of VPS within 10 to 240 ms [10]. Figure 3 shows the dependence of the required bandwidth for one call with the G.729 codec on selected VPS.

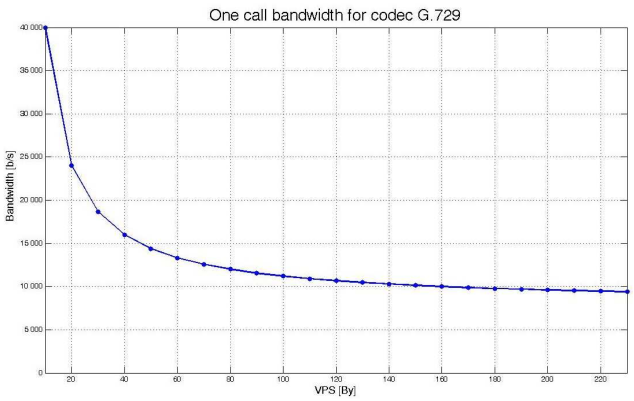

Figure 3. Dependence of one call bandwidth on VPS – G.729 codec.

The curves are not linear. Comparing low values of VPS to higher ones, it is evident that the significantly larger bandwidth to transfer one call is needed for low values. From the values of VPS = 100 ms, use efficiency of transmission line is almost the same. In this case, the required bandwidth for one call ranges around value of 11,2 kbit/s.

The default VPS value for Cisco equipment is VPS = 20 ms which corresponds to the bandwidth = 24 kbit/s. Thus, an appropriate setup of VPS can significantly affect the level of use of the transmission line.

Dependence of number of packets generated by end-terminal on the value of VPS is shown on Figure 4.

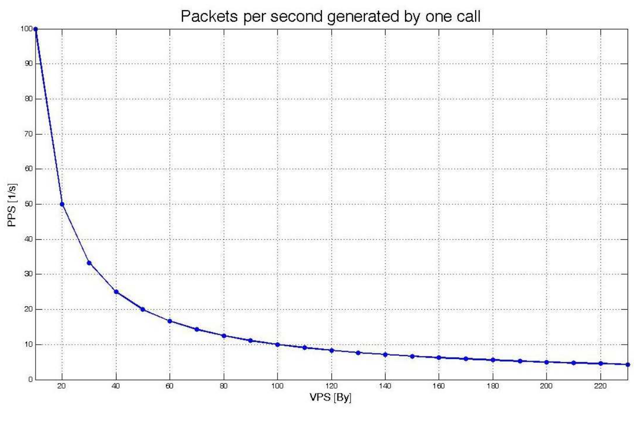

Figure 4. Dependence of number of sent packets on VPS.

Again, dependence is not linear. The VPS increase causes a significant reduction in the computational load of network nodes. As stated previously, we solve two contradictory requirements, saving of the bandwidth and minimum delay to obtain the good voice quality. It is logical that increase of the VPS takes effect in the increase of round trip delay. Round trip delay consists of the sum of the specific delays. VPS resize directly affects two of them and that packet delay and delay in buffers of end-terminals. (The buffers eliminate jitter.)

The VPS increase of 10 By corresponds to the VPI change to 10 ms. Therefore, delay in one channel (packet delay and delay in buffers) is increased by 20 ms, in the loop by 40 ms. G.114 recommendation sets the maximum round trip delay = 300 ms. The increase by 40 ms for each VPS increase by 10 By cannot be ignored. The dependence of rise of round trip delay on VPS is shown on Figure 5.

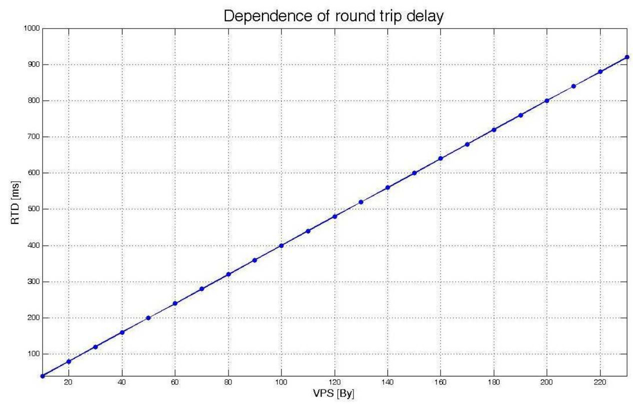

Figure 5. Dependence of rise of round trip delay on VPS.

With regard to the obtained results, we recommend choosing a compromise between the size of the VPS and the considered delay as follows: VPS = 60 By saves bandwidth by 80% with predictable delay in the loop = 240 ms. Therefore, we keep a sufficient reserve for possible increase of delay in the nodes and transmit delay.

V. CONCLUSION AND FUTURE WORK

When analysing the field network, we focused on its weak points. One of them is the bandwidth of E1 links. Although, the network uses the VAD mechanism and efficient G.729 codec to reduce the load generated by voice streams, we were looking for other options to streamline the voice traffic. We focused on verification of bandwidth depending on the voice payload size. From the calculations, it is clear that for small values of VPS, operation is very inefficient. In the next step, we evaluated a relation between VPS and round trip delay. We recommended VPS = 60 ms as the optimal value with respect to the G.114 Recommendation. Bandwidth saving up to 80 % can be done by this setting compared to the VPI default value = 20 ms. All consideration were carried out only at Layer 3 protocols.

Since transmission protocols of the Layer 2 have a significant impact on efficiency, we will focus our future work on this issue. In particular, we will test the operation of the field network for HDLC and PPP protocols.

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