OVERVIEW OF BROADBAND WIRELESS ACCESS TECHNOLOGIES AND STOCHASTIC MODELS FOR THEIR PERFORMANCE EVALUATION

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Abstract

A brief overview of the most important up-to-date broadband wireless access technologies is presented. Recent stochastic approaches for the performance evaluation of these protocols are explained.

1 Introduction

Nowadays information and communication technologies (ICT) are the core factor, which determines the development of economy. Their influence is twofold: firstly, it directly forms the gross domestic product; secondly, it improves the labor efficiency in the branches, where they are used. The importance of the rapid deployment of ICT for the developing economy of Russian Federation is difficult to overestimate [1].

The communication infrastructure, which currently exists in Russian Federation, has several drawbacks. First of all, communication networks are distributed extremely non-uniformly. In spite of the fact that high-speed mobile broadband wireless access is provided in bigger cities (like Moscow and St.-Petersburg), many settlements do not have even traditional fixed telephone connection. Additionally, often the quality and reliability of the existing infrastructure makes it impossible to provide contemporary information/communication services [2]. Therefore, in many regions of Russia broadband wireless access (BWA) does not have any rivals among wired networking technologies. Additionally, the following advantages of BWA can be emphasized: quick deployment, low costs, simplicity of maintenance, capability to cover the large territories, high speeds of subscriber's connections, capability to transmit the multimedia content, etc. This allows to solve the problems of Russian Federation's communication infrastructure efficiently from the economical point of view.

However, the number of available and being developed networking standards, architectures and equipment is so large that makes the problem of their performance comparison a challenging task even for the experts. WiFi (IEEE 802.11), WiMAX (IEEE 802.16), Universal Mobile Telecommunication System (UMTS), cdma2000, Long Term Evolution (LTE) are the examples of emerging wireless access technologies and mobile cellular systems [3], [4], [5]. In this paper we have tried to provide a brief performance comparison of the above technologies as well as to show some recent stochastic approaches for their performance evaluation. This paper aims to provide more clarity in the considered topic in the post-USSR region.

2 Overview of broadband wireless technologies

Here we provide some basic information on the most important characteristics of some broadband[1] wireless access and mobile cellular technologies:

1. WiFi is a common abbreviation for the products based on IEEE 802.11 standard and its amendments. Today the most widely used standard is IEEE 802.11-2007, which provides the channel rate of 54 Mbit/s for the frequency band 2.4 GHz (IEEE 802.11g). Typical cell radius is 50–60 meters [4], however there are examples of the deployments for the distances of up to 10 km [7]. QoS is supported by means of differentiation of traffic made by the variation in channel access time (IEEE 802.11e). New standard – IEEE 802.11n has been ratified in October 2009 and supports two frequency bands – 2,4 and 5 MHz and channel rate up to 300 Mbits/s. Working group Very High Throughput (VHT) is planning to finish up with new standard (up to 500 Mbit/s, below 6 GHz) in 2012. The support of mobility (handover) is being currently developed in the framework of IEEE 802.11r project.

2. WiMAX is a common abbreviation for the products based on IEEE 802.16 standard and its amendments. Today the most widely used standard is IEEE 802.16e (Mobile WiMAX), which provides the channel rate of 30 Mbit/s for the frequency band 2–6 MHz with the support of mobility. Typical cell radius is up to 70–80 km [4]. QoS is supported by means of differentiation of traffic by different bandwidth request/grants techniques and scheduling algorithms. New standard IEEE 802.16m (Advanced Air Interface) is being developed to allow higher data rates (more than 150 Mbit/sec).

3. UMTS and cdma2000 are European and American 3G (third generation) mobile cellular systems respectively[2]. According to [5] end user uplink data rate for 3G systems is up to 5.76 Mbit/s, downlink – up to 13.97 Mbit/s. In 2009 in the framework of UMTS the first versions of LTE (Super 3G, 3.9G) have been developed. It is expected that maximal downlink data rate will be 1000 Mbit/s and maximal uplink data rate will be 500 Mbit/s [3].

[1] Widely used term "broadband" has many meanings. According to the book [6] the system is called broadband if it uses signals for which frequency-time product is significantly larger than 1. According to the book [7] the system is called broadband if it has specific features and properties related to the broad frequency band: 1,25–40 MHz. For the aim of this paper we assume user-perspective definition of the broadband system: it is a system, which provides time-probabilistic characteristics of the transmission, which are sufficient for the normal operation of applications and services as well as user satisfaction. In other words in our context term broadband describes high-speed quality-of-service (QoS) supporting mobile wireless networks. Discussions about other definitions, their advantages and drawbacks can be found in [6], [7].

[2] The typical examples of previous generations of mobile cellular systems are as follows: 1G - analogous, voice, country-specific systems (NMT – Nordic Mobile Telephone, AMPS – Advanced Mobile Phone Service); 2G – GSM (Global System for Mobile communication); 2.5G – GPRS (General Packet Radio Service – approx. 48 Kbit/s); 2.75G – EDGE (Enhanced data rates for GSM – approx. 100–120 Kbit/s).

The above mentioned data rates for WiFi and WiMAX correspond to the physical layer aggregated per cell channel rates. End user rates will be *significantly lower* due to the following facts:

- there are many users in one cell;
- the communication channel is error-prone;
- there are multiple protocol-related overheads such as management frames exchanges;
- QoS-aware scheduling algorithms are vendor-dependent, and influence, in particular, the choice of modulation and coding schemes;
- typically there is a dynamic split of the allocated resources between the uplink and the downlink transmissions.

Therefore, performance evaluation of the above networks is a challenging problem. Different sources provide there own results for the performance evaluation of broadband wireless access equipment using field measurements and/or simulations [7]. These results vary depending on different external and internal factors, difficult for the analysis and often significantly vary, what motivates the researchers to develop simple and tractable analytical models of the protocol operation. Some of these analytical approaches are considered below.

3 Stochastic models of broadband wireless networks

The most recent approach to model IEEE 802.11e protocol analytically is presented in [9]. The idea of the method, which can be used to compute the network throughput is following. We assume that there are n stations in "saturation" conditions. Each station k belongs to some access category, which has specific values of the $AIFS$ (Arbitrary Interframe Space), W (contention window), R (retry limit) and $TXOP$ (transmission opportunity) parameters as defined in IEEE 802.11e.

Two underling discrete-time random processes $b_k(t)$ and $\{b_k(t),s_k(t)\}$, which represent the backoff counter and a pair – (backoff counter, backoff stage) of the k-th station at a time $t = 1, 2, ...$ respectively, is considered in [9] (t identifies the start of the tth cycle, where each cycle is composed of initial random waiting time plus exactly one transmission or collision event). Subsequent cycles are assumed to be independent. The following stationary distributions are considered:

$$G_k(j) = \lim_{t\longrightarrow\infty} Pr\{b_k(t) = j\},$$

$$S_k(s, j) = \lim_{t\longrightarrow\infty} Pr\{s_k(t) = s, b_k(t) = j\}.$$

The proposed model is solved through a fixed-point iteration, using as fixed point the set of distributions $G_k(.)$.

The most recent approach to model IEEE 802.16 protocol analytically is presented in [10], where reservation of bandwidth by means of random access prior to the transmission of data is considered. The idea of the method to compute the estimation of mean transmission delay is following. We consider the system from the point of view of the tagged station. We construct an embedded Markov chain at the sequence of begin times of the consecutive reservation intervals. The state of the chain consists of the number of packets in the subscriber station (SS) and base station (BS) buffers. More precisely we assume that there are three buffers for the data packets. The first buffer is the one at the tagged subscriber station where the packet is queued during the reservation delay. After that the packet is immediately transferred to the virtual buffer at the beginning of the corresponding reservation interval. The virtual buffer accounts for the fact that a packet cannot be transmitted in the current frame, that is experiences the delay of at least one frame. After this additional delay the packet enters the individual BS buffer of the tagged SS. There the packet is queued until the end of the scheduling delay. Finally, the packet is transmitted.

Let $\{A^{(t)}\}$, $\{B^{(t)}\}$ and $\{C^{(t)}\}$ denote the number of packets in the first buffer, in the virtual buffer and in the individual BS buffer at the embedded epoch in the t-th frame, respectively. The dynamics of the number of packets in the first SS buffer at the consecutive embedded time epochs in frame t and $t+1$ can be expressed by the following expression:

$$A^{(t+1)} = (A^{(t)} + G^{(t)})(1 - I^{(t)}),$$

where $G^{(t)}$ is the number of newly arriving packets, which enter the SS buffer during the interval between the t-th and $t+1$-th embedded epochs and $I(t)$=\{1 with probability of the successful bandwidth request transmission in a reservation interval and 0 otherwise\} is the discrete indicator function showing if the corresponding bandwidth request is transmitted successfully in the reservation interval of the t-th frame. The dynamics of the number of packets in the virtual buffer ($\{B^{(t)}\}$) could be described as follows:

$$B^{(t+1)} = (A^{(t)} + G^{(t)})I^{(t)}.$$

Finally, the evolution of the number of packets in the individual BS buffer ($\{C(t)\}$) at the embedded time moments could be written as:

$$C^{(t+1)} = C^{(t)} - J^{(t)} + B^{(t)},$$

where $J^{(t)}$=\{1, if $C^{(t)} > 0$ and 0 if $C^{(t)} = 0$\} is the discrete indicator function showing if the packet is transmitted successfully in the uplink sub-frame of the t-th frame. Then the steady-state mean number of packets in all three buffers is computed [10].

The stochastic approaches above illustrate that computation of time-probabilistic characteristics of contemporary broadband wireless networks is a complex problem; its solution allows to conduct the performance evaluation of the network and to have the input data for the deployment and modernization decisions.

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