Performance Comparison on the Last-Mile Access Segment for Different Wireless Technologies

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Abstract — **"Last-mile" broadband wireless access segment is the most challenging part of the wireless network. IEEE 802.11 Wireless LANs (WLAN) has been widely deployed to provide point-to-multipoint wireless broadband access in local areas such as offices, malls, and small companies. Most of the WLANs are connected to the backbone via a wired distribution system in a point-to-point connection. In this case, IEEE 802.11 wireless distribution system can be set up by connecting Access Points (AP) together to form multi-hop networks offering short-range "last-mile" solution. IEEE 802.16 Wireless MANs (WMANs) aim to extend the wireless broadband access up to kilometers in order to facilitate both point-to-point and point-to-multipoint connections. Thus, IEEE 802.16 offers the long-range "last-mile" solution. In this work, we address the "last-mile" data delivery segment issue in terms of transmission efficiency for IEEE 802.16 compared to IEEE 802.11.**

***Keywords* — last-mile access, transmission efficiency, 802.11, 802.16.**

I. Introduction

BROADBAND wireless communications have gained increased interest during the last few years [1]. The broadband wireless access approach to the "last-mile" access segment is becoming increasingly attractive to network operators and service providers since it offers a flexible and cost-effective solution to enable delivery of even broadband services to end customers.

The convergence of broadband wireless access will be the next storm in wireless communications, which will use a more generic configuration to wireless customers. Guaranteed quality of service (QoS) coupled with large bandwidth, and mobility makes these converged wireless systems a very attractive solution for "last-mile" broadband service delivery. Because the "last-mile" of a network to the user is also the first mile from the user to the network, "first-mile" is sometimes used.

Wireless Metropolitan Area Networks (WMANs) of the IEEE 802.16 standard are an upcoming competitor for conventional wired "last-mile" access systems. IEEE 802.16 realizes a fixed point-to-multipoint wireless broadband access system [2]. Various scenarios will arise, where 802.16 might have to compete with already deployed and operating Wireless Local Area Networks (WLANs) of 802.11 like in office and residential deployment scenarios [3].

Finally, the success of one technology is determined, not only by their contributions to the way people live, but also by their implementation and technical feasibility [4].

In this paper we first provide an overview of the 802.11 (WiFi) and 802.16 (WiMax) standards. Then a comparative performance on the wireless access segment of these two technologies is performed.

The study consist on analyzing (1) the effect of number of nodes and packet length, (2) the effect generated number of packets/second, (3) the influence of adaptive modulation, (4) the influence of mobility, (5) the effect of packet length for communications through the base station. The handover procedure was analyzed considering the effect of the mobile station speed over the link's parameters.

Transmission performances were extracted considering: (1) throughput, (2) jitter, (3) average end-to-end delays, (4) number of active sessions, (5) handover delays. For the study we used the ns-2 simulator. We have added a mobility package which implements IEEE 802.16 standard. The analysis conclusion recommends the implementation of the IEEE 802.16 standard even for the "last-mile" wireless access system.

II. IEEE 802.11 Standard

802.11 is the standard for Wireless Local Area Networks (WLANs) promoted by the Institute of Electrical and Electronics Engineers (IEEE). Wireless technologies in the LAN environment are becoming increasingly important and the IEEE 802.11 is the most mature technology to date. IEEE Standard 802.11 defines a Medium Access Control (MAC) and Physical Layer (PHY) specification for a wireless local area network to provide wireless connectivity for fixed, portable, and moving stations within a local area.

The IEEE 802.11 access scheme incorporates two access methods: Distributed Coordination Function (DCF) for asynchronous, contention-based, distributed access to the channel and Point Coordination Function (PCF) for

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centralized, contention-free access. PCF is intended to support real-time services (by using a centralized polling mechanism) [5], [6].

The two operational modes work in a cycle structure. The first time period called Contention-free Period or CFP is governed by the PCF mode and the second time period called Contention Period or CP is governed by the DCF mode.

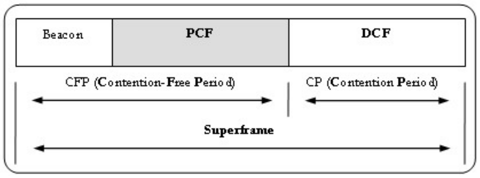

Figure 1. 802.11 Repetition Intervals.

The fundamental channel access mechanism of the 802.11 MAC is DCF mode, also known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). In order to avoid collisions, the DCF uses mechanisms for sensing whether the medium is in use before transmitting. DCF supports complementary physical and virtual carrier sense mechanisms. If the medium is in use, the station will wait according to a predetermined algorithm before attempting to transmit.

The CSMA/CA protocol is typically adopted in a wireless environment due to its reliability, flexibility, and robustness. To avoid the hidden terminal problem, the CSMA/CA protocols are extended with a virtual carrier sensing mechanism, named Request To Send (RTS)/Clear To Send (CTS).

The PCF is an access method similar to a polling system and uses a point coordinator to arbitrate the access right among nodes. With PCF, the period after each beacon transmission is divided into two sections which together constitute a superframe. This mode uses a Point Coordinator (PC). To gain access to the medium, the PCF mode uses the PIFS (PCF InterFrame Space) interval.

Using PIFS, the PC has the highest channel access priority. PCF provides collision-free access to the channel. Stations operating according to the DCF use the DIFS (DCF InterFrame Space) interval for transmission. Due to PIFS interval is shorter in duration than the DIFS interval, PCF based transmissions have a higher priority of access than DCF [7].

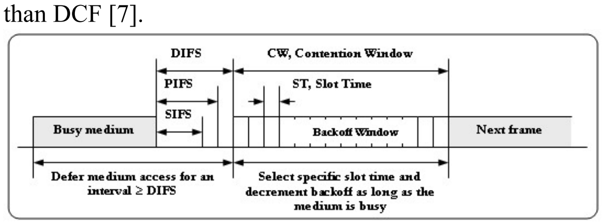

Figure 2. 802.11 Interframe Spacing.

III. IEEE 802.16 Standard

IEEE has been working on the standard for Wireless Metropolitan Area Networks (WMANs), which was IEEE 802.16. IEEE 802.16 standard is a technology which offers broadband wireless communications, for fixed and mobile topologies, in point-to-point and point-to-multipoint connectivity.

Since the IEEE process stops short of providing conformance statements and test specifications, in order to ensure interoperability between vendors the WiMAX forum was created. In much the same manner as the Wi-Fi forum assured equipment interoperability to the 802.11 standard, the WiMAX forum will provide the testing and certification necessary to assure vendor equipment interoperability for 802.16 hardware [8], [9].

The standard covers both the Media Access Control Layer (MAC) and the Physical Layer (PHY) layers.

The core components of an 802.16 system are the Subscriber Station (SS) and the Base Station (BS). A BS and one or more SS's can form a cell with a point-to-multipoint structure.

In contrast with 802.11 which uses contention access making services the 802.16 uses a scheduling algorithm for which the subscriber station need compete once. After that it is allocated an access slot by the base station. The time slot can enlarge and contract, but remains assigned to the subscriber station which means that other subscribers cannot use it [10].

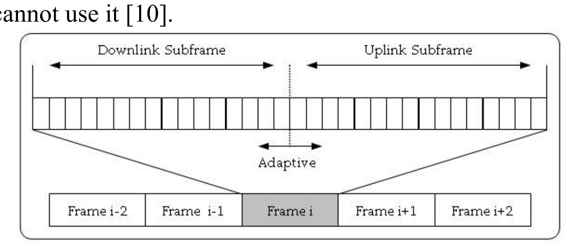

Figure 3. TDD Frame Structure.

The communication path between an SS and the BS has two directions: uplink, from the SS to the BS, and downlink, from the BS that may reach many SSs. Both uplink and downlink can operate in different frequencies using Frequency Division Duplexing (FDD) or share the same frequencies using Time Division Duplexing (TDD).

In both FDD and TDD systems, the uplink and downlink channels are structured into frames. In TDD, the frame is divided into two subframes, uplink and downlink subframes, where the uplink subframe follows the downlink Subframe. In FDD, the uplink and downlink subframes are concurrent in time but are carried on separate frequencies. All SSs and the BS have to be synchronized and transmit data bursts into predetermined time slots.

In uplink transmissions (SSs to BS), several SSs share the channel in a TDMA fashion. The Uplink Map Message (UL-MAP) is used to provide the channel access assignment to the subscriber stations [11], [12].

The UL-MAP which is transmitted by the base station at the beginning of the frame defines the uplink channel access as well as the uplink data burst profiles (UIUC) in the current uplink subframe. The SSs are allowed to transmit data bursts at predetermined time slots as indicated in the UL-MAP.

In downlink transmissions (BS to SSs), due to the fact that there is only one station (BS) transmitting the data, the channel access is rather simple. The data packets are transmitted by the BS to all SSs and an SS only picks up the packets destined to it. The Downlink Map Message (DL-MAP) is used to define the downlink data burst profiles (DIUC) in each time period in the current downlink subframe, in both TDD and FDD systems.

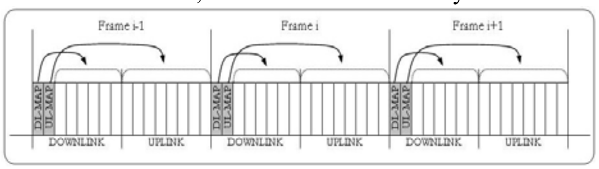

Figure 4. MAC Control Information (TDD).

The standard supports adaptive data burst profiling in which transmission parameters, such as modulation and Forward Error Correction (FEC) coding settings, can be modified individually to each SS on a frame-by-frame basis in both uplink and downlink transmissions. The standard allows three types of modulation schemes: Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM), and 64 QAM.

Different combinations of modulation and FEC provide different transmission robustness and transmission speed. Data burst profiles, which include parameters such as radio modulation type and FEC, are identified by a code called Interval Usage Code (IUC).

There are two types of IUC: Downlink Interval Usage Code (DIUC), which identifies the downlink data, burst profiles and Uplink Interval Usage Code (UIUC), which identifies the uplink data burst profiles. DIUC is included in a MAC message called Downlink Channel Descriptor (DCD) message; whereas, UIUC is included in the Uplink Channel Descriptor (UCD) message. DCD and UCD messages are transmitted periodically by the base station in order to define the downlink and uplink channel characteristics, respectively.

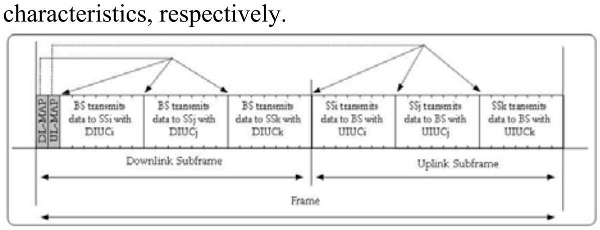

Figure 5. DL-MAP and UL-MAP indicate the starting time slot of each data burst.

The IEEE 802.16 group realized the need for multimedia applications and the required QoS support. Therefore, IEEE 802.16 has included a number of QoS signaling mechanisms [13].

IV. 802.11 COMPARTED TO 802.16 ON THE LAST-MILE ACCESS WIRELESS SEGMENT

In this paper we propose a performance comparison on the last-mile access segment for 802.16 compared to 802.11 in terms of (1) the effect of number of nodes and packet length, (2) the effect generated number of packets/second, (3) the influence of adaptive modulation, and (4) the influence of mobility. Also, the handover procedure was analyzed regarding the effect of the mobile station speed. Each scenario includes: (1) scenario description, (2) graphically representation and (3) results interpretation. Transmission performances were extracted considering: (1) throughput, (2) jitter, (3) average end-to-end delays, (4) number of active sessions, (5) handover delays. For the study we used the ns-2 simulator, version 2.29. We patched a mobility package which implements IEEE 802.16 standard, from National Institute of Standards and Technology, USA [14]. This patch contains an 802.16 model and a mobility package. The patch was developed in order to make publicly available modules for several wireless and wired technologies like: IEEE 802.3 (Ethernet), IEEE 802.15.1 (WPAN), IEEE 802.11b (WLAN), IEEE 802.16 (WMAN), and UMTS (WWAN).

A. The effect of number of nodes and packet length

The first analysis consists on testing the effect of number of nodes a packet length for 802.16 and 802.11.

Table 1: Simulation results for 10 transmitting nodes.

	802.16			802.11		
Packet size [bytes]	256	512	1024	256	512	1024
Ae2ed [ms]	1,13	1,23	1,38	3	4,6	15
Throughpu t [kbps]	420	800	1550	440	810	1200
Jitter [s]	$2x10^{-4}$	$2x10^{-4}$	$1.6x10^{-4}$	5.5	9	20
Tx nodes [number]	10	10	10	10	10	10

Table 2: Simulation results for 50 transmitting nodes.

	802.16			802.11		
Packet size [bytes]	256	512	1024	256	512	102 4
Ae2ed [ms]	1,13	1,23	1,38	22	30	32
Throughpu t [kbps]	1350	2600	5100	200	250	600
Jitter [s]	$2x10^{-4}$	$2x10^{-4}$	$1.7x10^{-4}$	33	46	193
Tx nodes [number]	50	50	50	50	13	7

Table 3: Simulation results for 100 transmitting nodes.

	802.16			802.11		
Packet size [bytes]	256	512	1024	256	512	1024
Ae2ed [ms]	1,13	1,23	1,38	60	66	76
Throughpu t [kbps]	1400	2700	5600	14	62	240
Jitter [s]	$2x10^{-4}$	$2x10^{-4}$	$1.7x10^{-4}$	55	57	63
Tx nodes [number]	62	62	62	62	2	6

We analyse the effect of transmitting nodes (10, 50, 100) cumulative with the packet size (256, 512, 1024) for 802.16 to 802.11 scenarios. The stations were placed randomly in a circle closer than 50 meters to the base station/acces point.

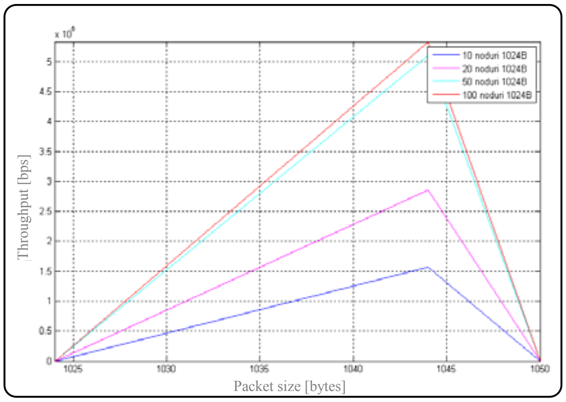

Figure 6. 100 nodes transmitting 1024 bytes packets size in an 802.16 scenario.

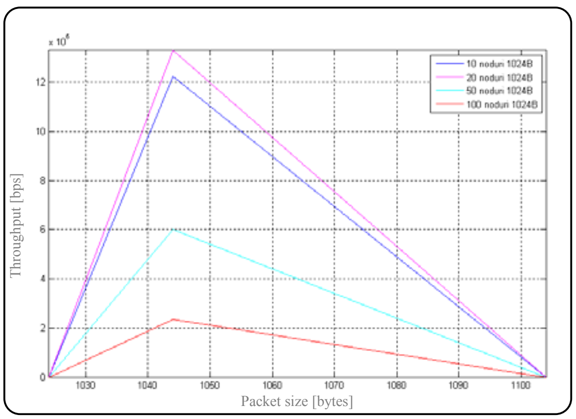

Figure 7. 100 nodes transmitting 1024 bytes packets size in an 802.11 scenario.

We can observe a decrease in quality of the network parametes for 802.11 compared to 802.16. Higher the number of possible transmiting stations, lower the number of transmitting stations. This is the result of (1) the possible reach of maximum transmitting stations in the given scenario, and (2) the medium access technique. Since 802.11 use contention-based access mechanism (CSMA/CA), for 802.16 is used a contention-less access mechanism (TDD). Using a more appropriate access technique, for 802.16 scenarios the best results are obtained even for the average-and-to-end delay, throughput, and jitter.

B. *The effect generated number of packets/second*

In order to evaluate the effect generated number of packets/second, we set up a scenario containing 100 nodes. Considering the previous scenario, this number of nodes offers the maximum number of transmitting nodes. Having a maximum of transmitting nodes, we expect a maximum of generated packets/second/station.

The packet size was selected 256 bytes. Each node will generate sequentially 10, 20, 100 packets/second.

Table 4: Simulation results for 100 transmitting nodes and different number of packets/second emitted.

	802.16			802.11		
Transmission [pack/sec]	10	20	100	10	20	100
Ae2ed [ms]	1,1	1,1	1,1	31	53	92
Throughput [kbps]	400	750	3500	180	120	5,5
Jitter [s]	$2x10^{-4}$	$2x10^{-4}$	$1.7x10^{-4}$	50	51	55
Tx nodes [number]	62	62	62	29	19	2

In a performance comparison analysis on the last-mile access segment, for the effect generated number of packets per second scenarios, we can observe best performances in case of 802.16 networks. All the analyzed parameters, including average end-to-end delay, throughput, and jitter recommend the use of 802.16 infrastructures.

C. *The influence of adaptive modulation*

In order to test the influence of adaptive modulation, we set up a scenario containing 20 nodes. For 802.16 scenarios, we set up QPSK1/2, QPSK 3/4, 16QAM 1/2, 16QAM 3/4, 64QAM 3/4 modulations, and for 802.11 we set up BPSK 1/2. Packet size is 1024 bytes and the source will generate 40 packets/second.

Table 5: Simulation results for 100 transmitting nodes and different number of packets/second emitted.

	802.16					802.1 1
Modulation	QPSK 1/2	QPSK 3/4	16QAM 1/2	16QAM 3/4	64QAM 3/4	BPSK 1/2
Ae2ed [ms]	48	35	28	17	1,7	35
Throughpu t [kbps]	860	1300	1720	2820	2850	1300
Jitter [s]	45	33	24	14	0.7	27

IEEE 802.16 standard define adaptive modulation on the physical layer. Adaptive modulation enables a 802.16 system to optimize the throughput based on the propagation conditions. Using adaptive modulation scheme, the system can choose the highest order modulation provided.

We can observe that when we use a higher order modulation, the average received throughput is higher. This scenario highlights a very important characteristic of 802.16, the adaptive modulation.

D. *The influence of mobility*

For the next generation technologies, mobility is more than a necessity, it's a requirement. Actual developed architectures dedicate a special attention to this aspect. In this scenario we will test the mobility effect in a handover process. A mobile node communicates with a base station and at a given time, the communications route is change from one base station to another.

The cell radius is 1000 m. Traffic type is CBR with 10 packets generated per second. Packets length is 4960 bytes. We will vary the mobile station speed from 1m/s to 5m/s, 15m/s, 30m/s.

Table 6: Cumulative effect of mobile nodes' speed and handover delay.

	802.16			
Modulation	1 m/s	5 m/s	15 m/s	30 m/s
Ae2ed [ms]	350	350	350	350
Handover delay [s]	0,005s	0,005s	0,005s	0,01s
Packet loss [packets]	5	8	8	21

Depending on which layer the roaming occurs we could define two major types of roaming: layer 2 roaming and layer 3 roaming.

A layer 2 network is defined as a single IP subnet and broadcast domain, while a layer 3 network is defined as the combination of multiple IP subnets and broadcast domains. Layer 2 roaming occurs when a mobile node moves far enough that its radio associates with a different access point. With layer 2 roaming, the original and the new access point offer coverage for the same IP subnet, so the device's IP address will still be valid after the roam.

Layer 3 roaming occurs when a mobile node moves from an access point that covers one IP subnet to an access point that covers another IP subnet. At that point, the mobile node would no longer have an IP address and default gateway that are valid within the new IP subnet.

In order to demonstrate the handover concept for IEEE 802.11 wireless LAN, a simple wireless scenario was realized. The so-called wired-cum-wireless scenario contains two wireless nodes, each of them communicating through its own base-station (AP).

The fixed network is simulated by a simple connection between the AP's and UDP traffic is set between the two mobile nodes using a CBR application. The rate is set to 100 kbps. In order to make possible the handover process, one of the nodes moves from the coverage area of one AP to the other one.

Table 7: End-to-end delays for user mobility on different wireless technologies.

Network type	Fixed network		Wireless network
Technology type	IP core		WLAN IP core
Handover decision	Layer 3		Layer 2
Protocol	IPv4	IPv6	IEEE 802.11
Handover delay [s]	0.007s	0.006s	0.004s

In order to compare 802.16 performances, there was simulated the handover processes also for mobile IPv4, mobile IPv6, and 802.11 [15]. Results presented in table 6 and table 7 indicates better performances for the handover delay in case of 802.16. A layer 2 (802.11) handover decision implies a less computational time on the mobile node vs. a layer 3 (IPv4, IPv6) handover decisions.

V. Conclusion

IEEE 802.16 (popularly known as WiMax) devices and networks are due to enter the market in a few years time from now. With IEEE 802.11 (popularly known as Wi-Fi) already widely prevalent, it is highly unlikely that 802.16 will totally replace it. It is most likely that both these technologies will coexist complementing each other.

Thus we need a set of parameters which are measured in both of these networks to better understand their behavior. This paper analyzed (1) the effect of number of nodes and packet length, (2) the effect generated number of packets/second, (3) the influence of adaptive modulation, and (4) the influence of mobility. Also, the handover procedure was analyzed regarding the effect of the mobile station speed over the link parameters.

Transmission performances were extracted considering: (1) throughput, (2) jitter, (3) average end-to-end delays, (4) number of active sessions, (5) handover delays.

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