WiBro (Wireless Broadband): An 802.16d/e Simulation Model

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Abstract

Samsung Electronics has been extensively contributing to Korea's WiBro (Wireless Broadband) initiative as well as the IEEE 802.16 standards. The WiBro is a specific subset of the 802.16 standards, specially focusing on supporting full mobility of wireless access systems with OFDMA PHY interface. In this work, we have developed a simulation model of the WiBro system consisting of a set of Base Stations and Mobile Subscriber Stations by using the OPNET Modeler. The simulation model has been utilized to evaluate effective MAC layer throughput, resource usage efficiency, QoS class differentiation, and system capacity and performance under various simulation scenarios.

Introduction

Recently, the IEEE has finalized the 802.16d standard [1], which specifies a set of different physical (PHY) and Medium Access Control (MAC) layers of Broadband Wireless Access (BWA) systems, which are Base Station (BS) and Subscriber Station (SS). The technology enables physically distant users to have access to the high-speed broadband wireless service with a relatively inexpensive cost comparing to existing cable and satellite solutions. In addition, the wireless coverage of 802.16 is much wider than that of 802.11 WLAN technologies while providing more bandwidth to users. Attracted by the above benefits, the industry has already been developing and selling commercial 802.16d systems and the market needs start to grow. Moreover, in order to promote the interoperability and compatibility of 802.16 products, numbers of companies organized the WiMax Forum [6] that offers the interoperability test among various products and fosters the development and commercialization of the products.

The 802.16 standard is not only for the fixed BWA systems, but also for the mobile BWA systems. The 802.16e standard [2], which is still being developed, provides the amendment for the 802.16d standard and extends the capability of 802.16 technologies to support subscriber systems with mobility. Samsung Electronics has been intensively working in 802.16e standardization and has contributed several important features of the 802.16e standard. Recently, Samsung has been elected to be a board member of WiMax forum to lead the mobile task group.

In Korea, the government and the industry has been working together to enable the wireless broadband service with mobility support during past years. (We named the service as Portable Internet previously, and then changed the name to WiBro.) We have our own standard [4,5], which is a subset of 802.16d/e, to encourage and accelerate nation-wide broadband wireless service. The initial draft service will be launched in the end of 2005. Korea will be the first country in the world to deploy the 802.16e service with the full mobility support by public service providers.

In this paper, we present a simulation model of Korea's WiBro systems using the OPNET modeler package including the wireless module. The simulation model consists of a set of BSs , mobile SSs, and several traffic handling node objects. Unlike the previous work [7,8], we have focused on modeling mobility of SSs and hand-over between different cells as SSs move around. We have executed various performance evaluation tasks to validate the correctness of modeling. Some of the simulation results are presented and explained in this paper. Since Samsung Electronics is currently developing the first WiBro systems as a system vendor, the simulation model is extremely helpful to understand the current performance limitation of WiBro specification, to design system architecture and deploy the device components in systems, and to improve and extend existing features before actual development of the systems.

In the next section, the detailed simulation model of WiBro systems is described. We briefly explain the current WiBro and 802.16d/e standard we referred to and how the standard features are modeled. Then, we show how we implement the various modeling components by using OPNET modeler v10.5. Several sets of simulation results are then presented to validate and utilize the modeling. Finally, our work with the simulation model is summarized and future work items are listed.

WiBro System Specification

Korea's Wireless Broadband (WiBro) initiative is pursuing to provide ubiquitous Internet access from various wireless devices with the mobility of up to 60km/h over a distance of several tens of kilometers in the multi-cell environment. It is launched by Korean government and several Korean companies, and the first commercial service will be opened in 2006 by a couple of service providers.

The WiBro specification [4,5] released by Korean Telecommunication Technology Association (TTA), is based on a subset of IEEE 802.16 standard. For the radio channel between BS and SS's, Korean government allocates 100MHz frequency bandwidth from 2.3GHz to 2.4GHz. WiBro specifies a communication channel of 9MHz bandwidth, thus, nine individual 9MHz channels are available. Over this radio channel, uplink and downlink access divides a fixed time interval, called frame. Among various physical layer schemes to organize a frame in 802.16, WiBro system only adopts Orthogonal Frequency Division Multiple Access (OFDMA) in Time Division Duplex (TDD) mode. The TDD frame length is 5 msec, and is segmented into the sequence of small fixed-duration logical units, called symbols. The frame structure is fixed as 27 symbols for the downlink subframe and 15 symbols for the uplink subframe. The detailed WiBro frame structure is depicted in Figure 1. (The narrow gaps between subframes are ignored.)

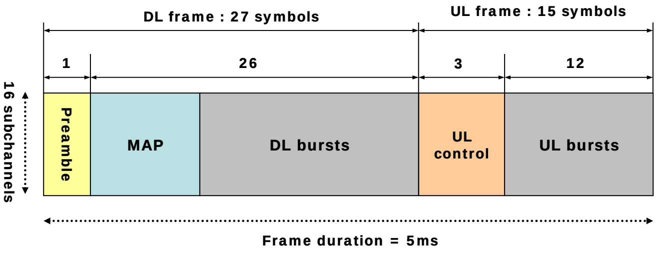


Figure 1: WiBro OFDMA TDD Frame Structure

The encoded data bits are transmitted over a set of subcarriers in wireless communications. In the WiBro specification, there are 864 subcarriers (FFT size is 1024) within 9MHz bandwidth. A set of subcarriers composes a logical transmission unit, called subchannel. While there are several different ways of constructing a subchannel from subcarriers according to the location of subchannels within subframe, the number of subchannels is 16 (in FUSC mode) in the WiBro specification. The unit symbol time of a single subchannel is defined as a slot. This slot is the logical encoding unit of wireless transmission. A bit stream is encoded into a slot, in other words, the bit stream is carried by a subchannel during the period of a symbol time.

For downlink, 26 symbol times are available for logical maps and downlink bursts, while 12 symbol times are available for uplink bursts for uplink; 416 slots for downlink and 192 slots for uplink. The MAP consists of Frame Control Header (FCH), DL-MAP (downlink map), and UL-MAP (uplink map). The maps guide SS's how to decode the following data bursts. The burst is a set of actual data slots that are allocated by a BS, for either downlink or uplink. SS's are informed when and on which subchannel they need to decode data for downlink, and to encode data for uplink. The BS is responsible for organizing the maps and the bursts in every frame.

The 802.16 MAC messages are transferred in each burst. The WiBro specification uses the same MAC message format as 802.16. The MAC message has user payload, 6-byte fixed MAC header, optional 4-byte CRC and optional 12-byte encryption data. There is no difference, when it comes to the functionality and the format of MAC messages, between WiBro and 802.16. In addition to the messages in 802.16d, WiBro adopts standard messages defined in 802.16e for mobility support. Hand-over mechanisms and sleep mode operations are two main features added for the mobility support.

The uplink control information subframe is a collection of special-purpose control channels and uses three dedicated symbol times in the uplink subframe. Initial and periodic ranging channels are used for SS's to make network entry and adjustment to wireless channels. Channel Quality Indication (CQI) channels for reporting the previous channel quality and acknowledgement data for Hybrid ARQ (H-ARQ) are included in the control information as well.

The uplink transmission is operated in the bandwidth request and grant mechanism. SS's should request a certain amount of bandwidth to BS first when it has some data to transfer, and BS allocates uplink bursts to the SS's after scheduling decisions. There are four different bandwidth allocation service types; Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), non-real-time Polling Service (nrtPS), and Best Effort (BE) service. They are different in how the bandwidth request and grant messages are exchanged between SS and BS. Every uplink session is mapped to one of the service types. The BS is responsible for uplink scheduling as well as downlink scheduling at the same time.

Simulation Modeling with OPNET

OPNET Modeler [9] is a powerful discrete-event simulation tool with easy and convenient development environment and GUI. We used OPNET modeler 10.5 with Wireless Module to develop the simulation models of our WiBro systems. The top-level network browser view of our WiBro simulation model is captured as in Figure 2.

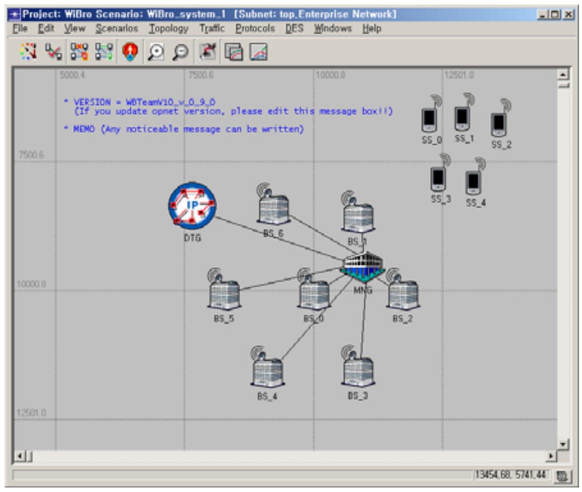


Figure 2: WiBro System Model in OPNET Network Browser

There are seven BS nodes connected to MNG node, and the MNG node is connected to DTG node. SS nodes are located separately. The DTG (dynamic traffic generator) node represents traffic source and destination for communicating with SS's. The MNG (management) node represents a centralized router working as backbone network of BS nodes. While the number of SS nodes can be flexibly changed, the number of BS nodes should be fixed to seven to model SS mobility and hand-over between hexagonal shapes of BS cells as in Figure 3.

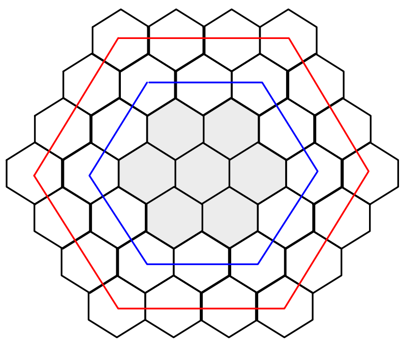


Figure 3: BS Cell Modeling

The seven BS nodes represent seven shaded cells in the center of Figure 3. The radius of a cell is 1000 meters and the initial location of each SS node is randomly given within the shaded area at runtime of simulation. The white cells around the shaded cells are virtual cells to calculate interference and to support wrap-around feature of SS movement. Every shaded cell has six 1st tier neighbor cells and twelve 2nd tier neighbor cells that cause interference. We assume cells farther than 2nd tier cannot add more interference.

The SS node is modeled to have one of three different types of mobility as summarized in Table 1. When an SS moves out of a cell, appropriate hand-over steps are performed by the SS and two participating BS's. Instead of using OPNET's trajectory modeling, we implemented our own wrap-around modeling for the movement of SS's to be more general. If an SS moves out of the coverage of shaded cells, we virtually moves SS's going out of one cell to the cell in the opposite direction. For example, if an SS moves from the gray cell of 6 to the white cell of 4, the SS is considered to move from the white cell of 6 to the gray cell of 4. With the cell deployment and mobility modeling, we can generalize our model to be applied to any scenario of WiBro system configurations.

Table 1: SS Mobility Types

Mobility Types	Speed of SS	Direction Change Scheme (default: at every 30 seconds)
Stationary	0 km/h	No change
Pedestrian	3 km/h	One of 90,180,270,360 degree
Vehicular	60 km/h	One of any degree in 0~360

When the mobile SS travels across multiple BS cells, the hand-over steps defined in 802.16e are performed at each cell cross. Each mobile SS registers a 'serving BS' when it first enters WiBro network. The serving BS provides network access to the subscribed BS's. When there are multiple BS's sending broadcast messages to SS's, one SS can detect the signal from non-serving BS's and considers them as candidates of 'target BS' by keeping records of the signal power from the candidate BS's. If the signal power of a target BS is stronger than that of the serving BS and maintains the relative strength for a certain period of time (0.3 sec in our simulation), the hand-over steps are performed. The user traffic from/to the moving SS is paused for a short period of hand-over operations, and then resumed.

The BS node is modeled as in Figure 4. There are three main processors/queues corresponding to the sublayers in 802.16 standards; convergence sublayer, MAC sublayer, and PHY sublayer. The MAC sublayer contains subqueues to classify uplink and downlink traffic streams by their connection IDs. Radio transmitter/receiver and antenna object from OPNET Wireless Module are used to model the wireless interface to SS's.

The SS node is modeled as in Figure 5. In addition to the similar processors/queues in BS node model, there are traffic generator processor and mobility processor in the SS node model. The traffic generator models high-layer applications. We implemented four different application types; VoIP, video streaming, HTTP, and FTP. In order to resemble actual application behaviors over wireless channels, the applications are modeled by 3GPP2's 1xEV-DV application profiles [3]. The traffic generator is flexible to launch any number of application sessions with pre-defined patterns. The mobility processor is for initializing and updating the location of SS periodically during simulation runs. The (x, y) location coordinator of SS is maintained by the mobility processor.

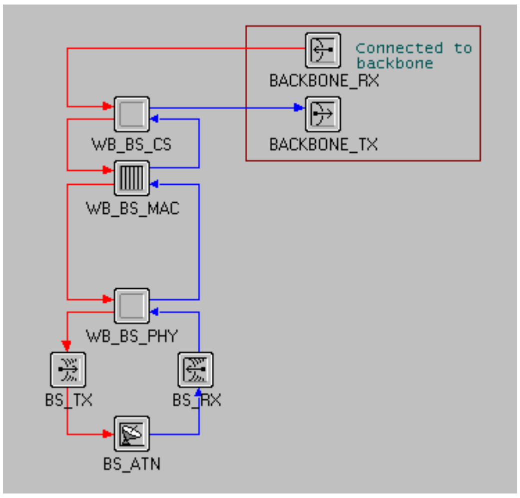


Figure 4: BS Node Model

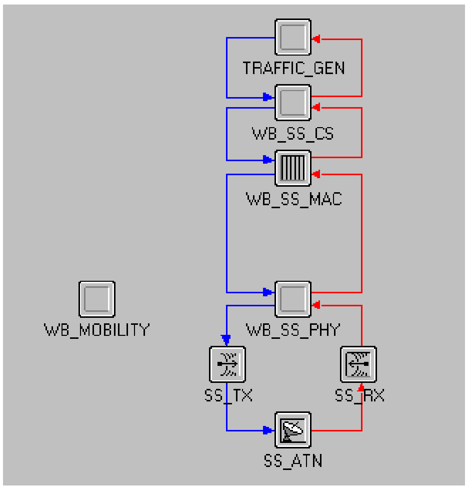


Figure 5: SS Node Model

The physical wireless channel between BS and SS is basically modeled by using OPNET's pipeline stages. However, because the default pipeline stages are modeling only simple TDMA type of wireless channels, we add our own schemes for modeling OFDMA wireless channels. The WiBro system's OFDMA channel has 864 subcarriers of different frequency selection. Since creating 864 individual OPNET wireless channels is totally inefficient, we only virtually model 16 subchannels in WiBro PHY specification within a single OPNET wireless channel. The pathloss fading and shadowing effect is calculated within our own pipeline stages. However, the interference and the modulation schemes of 16 subchannels are separately calculated within PHY processor of BS and SS nodes.

In order to accurately model the wireless physical channels, we use results of Samsung's wireless link-level simulations, which are not available to public at this time. Based on the results we set up two relation tables, one for uplink and the other for downlink, which consist of Signal to Interference Ratio (SINR), index of Modulation and Coding Scheme (MCS) level, Packet Error Rate (PER), and speed of mobile SS's. The number of MCS levels for uplink is 8 (from QPSK 1/12 to 16QAM 2/3), and for downlink, the number of MCS levels is 11 (from QPSK 1/12 to 64QAM 5/6). In OPNET simulation, we prepared the tables in OPNET's GDF file format and the tables are loaded at the initial simulation runtime.

The GDF tables are looked up twice at each wireless packet communication; one at transmission time and next at receiving time. When in transmission operation, the transmitter needs to determine the MCS level by using (SINR, PER, speed) values. The SINR of previously received burst profile is known by using CQI feedback. The PER is target PER of 0.01, which is given as a global attribute. The speed of SS is fixed and easily obtained. Thus, referring to the appropriate GDF table (either uplink or downlink), the MCS level that satisfies the target PER under the constraints of current SINR and speed of SS is selected.

When in receiving operation, the receiver needs to determine the PER by using (SINR, MCS, speed) values. The SINR is calculated by considering various fading effects on the transmitted signal power and interference signal accumulations. The MCS level of burst profiles is written in the profile header information and the speed of SS is fixed. Thus, the GDF table gives PER value of currently received burst profile. The PHY processor drops the burst at the probability of the given PER.

Simulation Results – Basic Verification

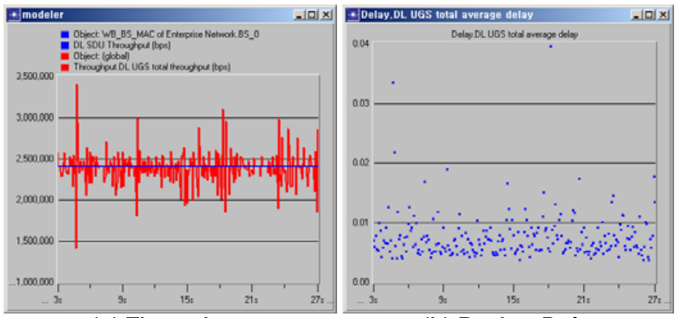
In order to obtain the maximum ideal throughput of WiBro systems as reference values, we first assume best conditions of wireless channels; one BS and one fixed SS experience ideal SNR and less than 1% of packet error rate. Thus, they are able to utilize the full capacity of wireless resources by using the best modulation scheme (64QAM 5/6 for downlink and 16QAM 2/3 for uplink) all the time. Table 2 lists the maximum user data (excluding MAC and PHY overhead) throughput values when the overloaded CBR user traffic with the packet size of 1500 bytes is given.

Table 2: Maximum User Data Throughput

Traffic Direction	Bandwidth Allocation Service Type	Maximum Data Throughput
DL	N/A	16.487 Mbps
UL	UGS	4.895 Mbps
	rtPS	4.892 Mbps
	nrtPS	4.794 Mbps
	BE	4.793 Mbps

Due to the asymmetric frame design and different modulation schemes, the maximum throughput for downlink is about 3.37 times more than that for uplink. Among different bandwidth allocation service types in uplink, UGS and rtPS show slightly more throughput than nrtPS and BE because nrtPS and BE enable MAC ARQ in our simulation. The maximum throughput of WiBro is comparatively better than that of symmetric 802.11b WLAN (5.5Mbps theoretically [11]) and that of asymmetric CDMA 1x EV-DO (3.1Mbps for downlink and 1.8Mbps for uplink [13]) and WCDMA HSDPA (14Mbps for downlink and 2Mbps uplink [12]). However, in reality, due to the unreliable wireless channel conditions and scheduling overhead, the actual throughput is usually smaller than the ideal maximum throughput.

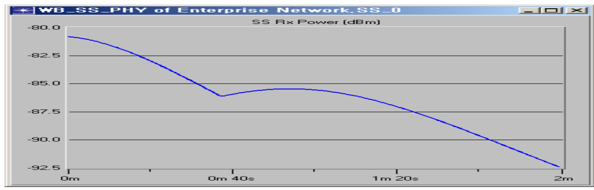
In order to simulate WiBro systems in actual wireless environment, we now enabled all the seven BS's and the wireless channel modeling with various fading and interference. Figure 6 presents an example of downlink CBR traffic over the WiBro wireless channel model. The traffic load is 2.4Mbps with the packet size of 1500 bytes. Because of the dynamic changes of modulation schemes according to the wireless channel conditions, the actual user data throughput received by SS MAC layer fluctuates as in (a) and the packet delay varies up to 40msec (8 frame time delay) as in (b).



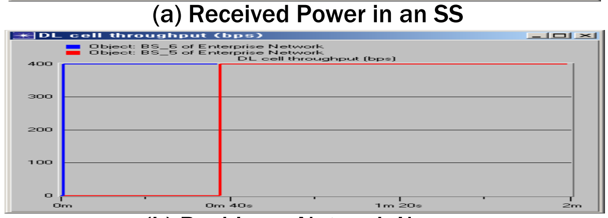
(a) Throughput (b) Packet Delay

Figure 6: Example Downlink CBR Traffic

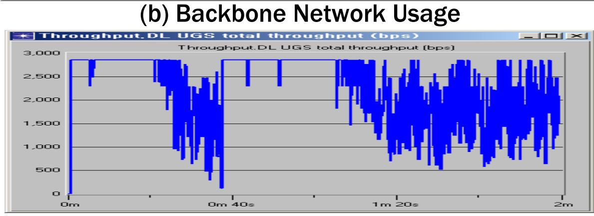
Next, we verify the hand-over mechanisms of mobile SS when it leaves an existing cell and enters a new cell. Figure 7 shows a typical hand-over example when a hand-over happens at the time of 37.81 sec.



(a) Received Power in an SS



(b) Backbone Network Usage



(c) Actual Downlink User Data Throughput

Figure 7: Example Downlink Hand-Over Trace

When a mobile SS travels (60km/h in this example), the received signal power varies as in (a). At the hand-over point, the signal power from a new BS (BS_5) becomes higher than the signal power from the previous BS (BS_6) and the SS decides to move to the new cell. The downlink backbone traffic has been sent to BS_6 is now forwarded to BS_5 as in (b). The actual throughput of the downlink CBR session measured in SS fluctuates around the hand-over time due to increased interference at the cell boundary as in (c).

Now we compare the effects of different uplink scheduling service types. Figure 8 shows packet delay of CBR sessions each represents one of four different scheduling services. We configured 100 uplink sessions (25 sessions for each scheduling service type) competing for the limited uplink resources.

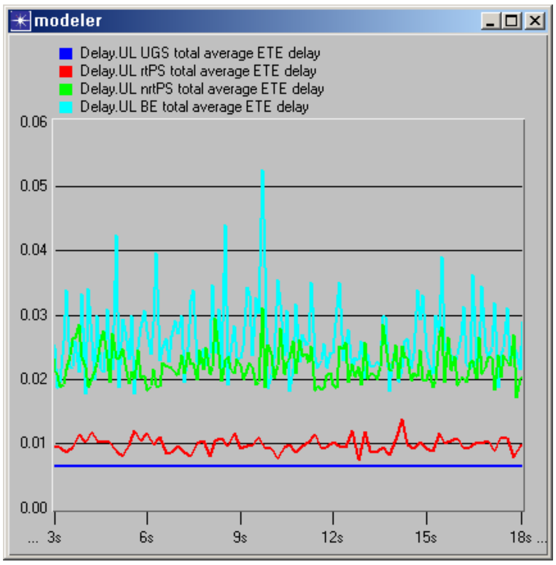


Figure 8: Comparison of UL Polling Services

As depicted, the polling services which guarantee QoS, UGS and rtPS, show smaller and consistent packet delay while two other polling services, nrtPS and BE, show longer and fluctuating packet delay. As the current uplink scheduler uses strict-priority scheduling algorithm (UGS > rtPS > nrtPS > BE) among different polling service types, the above result is straightforward.

Simulation Results – Capacity Planning

First, we measure the average downlink throughput of a BS while increasing the number of mobile SS's having a single downlink CBR application session. The CBR application generates a packet in every 10msec. The wireless channel of a BS is being saturated when we increase the number of SS's. We use the simple round-robin scheduling scheme in the BS scheduler. In order to investigate the impacts of packet size, we use five different packet sizes; 150, 300, 500, 1000, and 1500 bytes. As the inter-arrival time between packets is constant, the traffic load increases proportionally.

The average downlink data throughput which is the sum of average data throughput of all SS's stops increasing when the wireless channel reaches to the saturation level as in Figure 9. Comparing to the ideal maximum throughput, 16.487Mbps, in Table 2, we found the maximum throughput under real situations is less than a half of the ideal value. Moreover, we noticed that the saturation level is increasing as the packet size increases. The behavior is explained as more bandwidth is required for MAC headers in the cases with smaller packet sizes because there should be more number of packets to make the wireless channels to be saturated. It is more likely to have more number of downlink packets in each frame for the cases with smaller packet sizes. Note that the size of MAC headers is proportionally increasing when the number of packets increases.

The packet delay depicted in Figure 10 shows opposite results. The longer is the packet, the less number of packets are successfully delivered to SS within 20msec delay bound. In the case of 1500-byte packets, only 25% of packets meet the bound when saturated, while 50% of packets survive in the case of 150-byte packets even in the same saturated situation. It is obvious because longer packets are likely to be segmented into several MAC-PDUs to be stored in variable-size DL-bursts and then a packet is successfully delivered only when all the segments are delivered correctly.

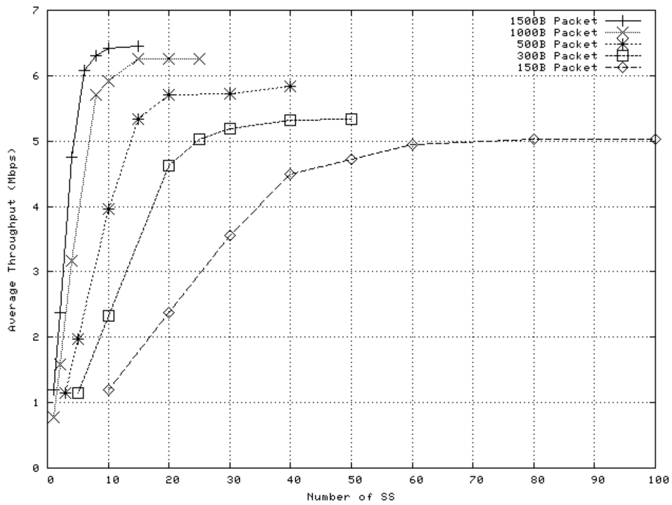


Figure 9: Average Data Throughput of All DL CBR Traffic

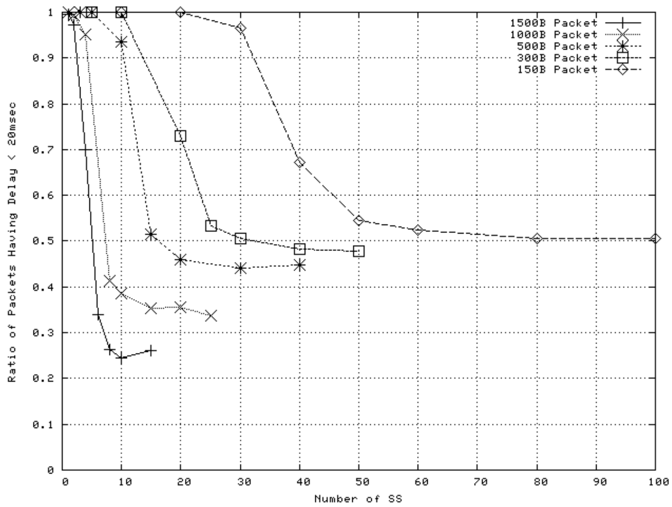


Figure 10: Ratio of Packets Having Less Than 20ms Delay

Next, we set up VoIP application traffic and investigate the capacity of a single BS system when handling numbers of mobile VoIP users in order to perform more realistic analysis. The VoIP application traffic modeling is based on Enhanced

Variable Rate CODEC (EVRC) used in CDMA systems. A VoIP session repeats talk-spurt period and silence period, in other words, on period and off period as in Figure 11.

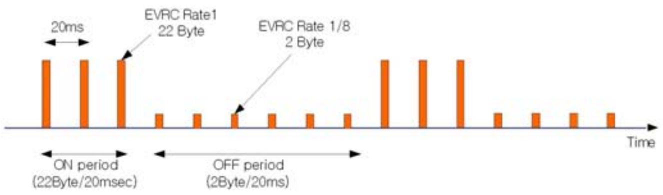


Figure 11: VoIP EVRC Payload Model

Within the on period, 22-byte payload is sent in every 20 msec (EVRC Rate 1). During the off period, only 2-byte payload is sent (EVRC Rate 1/8). The length of the periods follows the exponential distribution; the mean time for the on period is 0.352 sec and 0.650 sec for the off period. In addition to the payload, 40 bytes of IP/TCP/RTP headers are added in uncompressed header mode. In compressed header mode, the header size is compressed to only 4 bytes.

While increasing the number of mobile SS's each running VoIP application, we measured the packet delay between BS and SS both in uncompressed header mode and compressed header mode. The measured result is presented in Figure 12. Due to the asymmetry between downlink and uplink capacity, the symmetric VoIP application experiences bottleneck in uplink direction first. The UGS uplink scheduling type is used for the VoIP application and the scheduler in BS performs round-robin scheduling among many SS's.

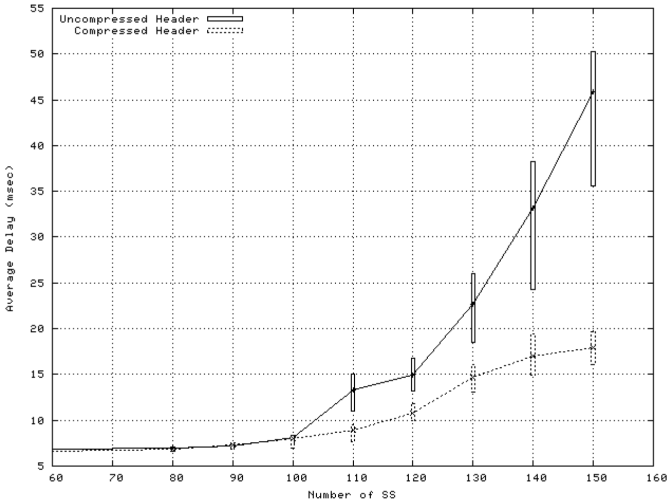


Figure 12: Average VoIP Packet Delay

When the number of SS reaches to 100, the uncompressed VoIP sessions starts experiencing more packet delays and the gaps between average delays of uncompressed VoIP sessions and compressed VoIP sessions becomes wider as the number of VoIP sessions increases. The box represents delay range between 1st quartile and 3rd quartile of each packet delay measurement. As shown, the difference between two quartiles is also increasing as the number of VoIP sessions increases. With the simulation results, the capacity of WiBro systems is easily projected. If we want packet delay to be less than 20msec, the number of uncompressed VoIP sessions should be controlled to be less than 120. However, we can accept 150 VoIP sessions by using compressed header mode instead.

Summary and Future Work

In this work we presented an 802.16d/e simulation model named WiBro. The WiBro as well as 802.16d/e systems will not only give wireless users another option of wireless access, but also enable new advanced wireless broadband access by providing much more bandwidth with full-mobility support. As Samsung Electronics plays a leading role in developing WiBro systems and preparing the world-first commercial WiBro service in Korea in 2006, the WiBro simulator is expected to be used in designing actual WiBro system features in many aspects. With OPNET v10.5 modeler package, we implemented the WiBro simulator by modeling OFDMA frame structure, MAC messages, cell architecture, and SS mobility.

In order to validate the functionality of the WiBro simulator, we showed several simulation results. First, the ideal maximum throughput of downlink/uplink channel is verified to show the competitiveness of WiBro standards over existing CDMA, WCDMA or WLAN systems. Then the capacity of actual WiBro systems using mobility modeling of SS's is measured. The maximum capacity of CBR traffic as a general load case and the capacity of VoIP application sessions as a specific real-world example are measured. In both cases, the WiBro simulator gives enough information to understand how much system capacity is used at the given system load. By using this information important system parameters can be analyzed and determined when designing actual systems.

Future work includes expanding the simulator to model real WiBro systems Samsung currently develops, enhancing BS scheduler with the proportional fair scheduling algorithm, modifying existing traffic models to adopt OPNET's built-in traffic models as well as TCP/IP stacks, and also verifying mobility support functions which are not fully investigated in this paper.

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