

Capacity Analysis Considering Channel Resource Overhead for Mobile Internet Access(WiBro)

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Abstract—Wireless mobile internet access is becoming an important segment for the wireless industry. In this paper the new system, WiBro, being standardized in Korea is introduced. We address some of the physical layer aspects and the corresponding impacts on system performance. To provide the solution for optimized network operation, we evaluate the capacity of WiBro in various network conditions with the developed system level simulator. Simulation results provide insight on how performance varies within the coverage area according to the values of system parameters. Also, we derive the adequate values to maximize capacity considering channel resource overhead.

Keywords—Wireless mobile internet system, WiBro, system level simulator, capacity, Optimized network operation

I. INTRODUCTION

The growing demands for advanced mobile multimedia let the wireless mobile internet access be developed rapidly. The new system named ‘WiBro’ is proposed in Korea and is being standardized. WiBro means wireless broadband internet. It is to provide wireless internet access with PSS (Portable Subscriber Station) under the stationary and medium-speed mobile environment.

Some of the advantages of integrating cellular with WiBro include high data rate, low cost, the ubiquity of hot spots, and the offload of cellular spectrum. WiBro offers high-speed data service within specific and usually small areas. Wireless mobile systems, on the other hand, provide the wider area of service. The data rates with wireless mobile are however significantly slower than WiBro. This makes the integration of the two access technologies highly complimentary.

WiBro service should provide seamless connectivity regardless of the place and time. Service shall support the various types of wireless multimedia applications and the various types of multimedia-enabled terminals such as handset, notebook, PDA, or smart phone. Service consists of three classes: real-time service, non-real time service, and best-effort service. Real-time service imposes delay constraints while requiring the guaranteed resource allocation during the session such as audio/video streaming and interactive game. Non-real time service does not impose any delay constraints while requiring the guaranteed resource allocation during the session

such as ftp and e-commerce. Best-effort service does not impose any delay constraints while requiring no guaranteed resource allocation the given service such as web browsing and e-mail [1] [2].

Coverage of WiBro must be supported for the different cell types in the urban environment: pico-cell(100m), micro-cell(400m), macro-cell(1km). System shall support mobile users at a velocity of up to 60 km/hr and seamless IP-based service while users move to another cell, and inter-working with other network systems such as wireless LAN and other mobile communication networks. Also, WiBro provides the following data rate: 1) Minimum data rate per user: downlink=512 kbps, uplink=128 kbps, 2) Maximum data rate per user: downlink=3 Mbps, uplink=1 Mbps [3] [4].

WiBro will increase the market for broadband wireless access solutions by taking advantage of the inherent mobility of the wireless media. It is expected to fill the gap between very high data rate wireless local area networks and very high mobility cellular systems. SK Telecom providing various mobile services through cdma2000 1X, 1x EV-DO, and WCDMA systems has a plan to launch it in 2006 for the next mobile communication service

The organization of this paper is as follows. In Section II, the key features and specification of WiBro are introduced in detail. Channel resource overhead is derived in Section III. In Section IV, the analysis of CINR, coverage, and capacity is addressed. Finally, conclusions are drawn in Section V.

II. KEY FEATURES AND SPECIFICATION OF WiBro

WiBro has physical layer properties based on OFDMA that allows high bit rate transmission on frequency selective channels with a relatively low complexity. It uses TDD method designed to be more spectral efficient than FDD method when involving asymmetrical internet traffic. Its frame length is 5 ms which has 42 OFDMA symbols. It operates in the 2.3 GHz band.

Specification of WiBro is summarized in table 1. Fig.1 shows the frame structure. Its channel bandwidth is 10MHz with 1024-FFT. Channel consists of the fast AMC (Adaptive Modulation and Coding) sub-channels based on uplink CQI

(Channel Quality Indicator). Sub-channels are flexible for band selection and diversity. Fixed wireless indoor service is supported with band selection mode to maximize multi-user scheduling gain by utilizing channel selectivity for stationary users. And mobile wireless outdoor service is supported with diversity mode to maximize wideband frequency diversity and temporal diversity gain for mobile users. Also, various modulation levels with code rate are supported: QPSK, 16QAM, and 64QAM(Downlink only).

Refer to fig. 1. A bin is composed of 9 consecutive tones (8 data tones+1 pilot tone) in downlink channel and uplink channel except diversity mode. Band selection channel in uplink is partitioned into tiles which are 3x3 frequency-time block containing 9 tones (8 data tones+1 pilot tone). One sub-channel consists of 6 consecutive bins.

The first one OFDMA symbol in downlink is allocated to preamble for initial synchronization, cell searching, and channel estimation. PUSC (Partial Usage of Sub-Channels) has two symbols for sectorization and partial loading. It means limited frequency diversity. The proportion of diversity to band selection can be changed every frame.

Uplink dedicated control channel consists of CQI, ACK, Ranging channels. CQI channel is used for C/I feedback for link adaptation with 8-ary orthogonal coding (QPSK symbol is used) and 1 uplink sub-channel is allocated to a CQICH (6tiles). ACK channel is used for H-ARQ (Hybrid Automatic Repeat and reQuest) with 8-ary orthogonal coding (QPSK symbol is used). H-ARQ is used for high quality and low latency in the downlink/uplink. A half of uplink sub-channel is allocated to an ACK/NAK CH (3tiles). Ranging channel is based on CDMA ranging. Ranging modes are differentiated by code and time slot and users are allowed to collide on the ranging channels. Two OFDMA symbols are for initial ranging/bandoff ranging and one OFDMA symbol is for periodic ranging and bandwidth request. In uplink, also, the proportion of diversity to band selection can be changed every frame.

Specification of WiBro is somewhat similar to IEEE 802.16e, but there are some different characteristics. The big differences are the structure and performance of preamble, sub-carrier permutation in FCH/DL MAP, the existence of idle mode/paging, and so on.

TABLE I. SYSTEM PARAMETERS

System Parameters	Value
Sampling Frequency	10 MHz
Number of used tones	864 out of 1,024
Numver of data tones	768
Number of pilot tones	96
Tone spacing	9.765625 kHz
Signal Bandwidth	8.447 MHz
Basic OFDMA symbol time	102.4 μ s
Ratio of cyclic prefix to the OFDM symbol	1/8
OFDMA symbol time	115.2 μ s
TDD frame length	5 ms
Number of symbols in a frame	42

System Parameters	Value
TTG+RTG	161.6 μ s
Number of tones per bin (DL/UL)	9(8 data+1 pilot tones)
Number of tones per tile(UL)	9(8 data+1 pilot tones)
Number of bins per AMC sub-channel(DL/UL)	6
Number of tones per diversity sub-channel(DL)	48 data tones
Number of tiles per diversity sub-channel(UL)	6

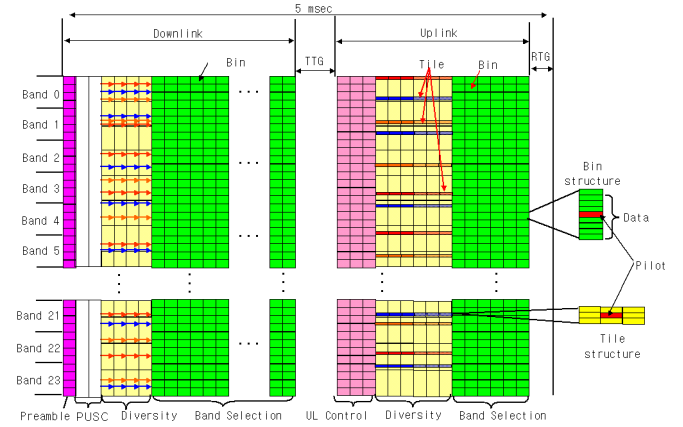


Figure 1. Frame Structure

III. CHANNELRESOURCE OVERHEAD ANALYSIS

The performance of WiBro is evaluated in terms of channel resource overhead, coverage, and capacity. In this section, we analyze the channel resource overhead and compare it with cdma2000 1X.

Channel resource overhead is the ratio of channel resource used for non-data to total channel resource in one frame which consists of time and frequency domain. It is variable according to the network operation condition i.e. the proportion of downlink to uplink.

$$\text{Overhead} = \frac{(\text{control channel} + \text{pilot resource} + \text{TTG} + \text{RTG})}{(1 \text{ Frame channel resource})} \quad (1)$$

$$= \frac{\{(\text{control symbols} \times T_s \times \text{subcarriers}) + (\text{pilot symbol} \times T_s \times \text{subcarriers}) + (\text{TTG} + \text{RTG}) \times \text{subcarriers}\}}{(1 \text{ frame duration} \times \text{subcarriers})}$$

where T_s is symbol duration. TTG is transmit/receive transition gap and RTG is received/transmit transition gap.

Fig. 2 shows the channel resource overhead according to DL:UL when map message is 1 symbol. Downlink has the overhead variation from 27.44% to 21.69 %. Uplink does the wide overhead variation from 25.06 % to 42.96 %. Overhead varies inversely as link portion. In most cases uplink overhead is higher than downlink overhead. The low ratio of uplink to downlink and allocated three symbols for control channels cause the high uplink overhead. We derive that the proper link proportion is 2:1 for DL:UL in consideration of both link overhead balance and asymmetric wireless data characteristics.

From Fig. 2 we know that total channel resource overhead remain unchanged by different link proportion. Total 1 frame overhead is 26.27 %. Although channel resource overhead in

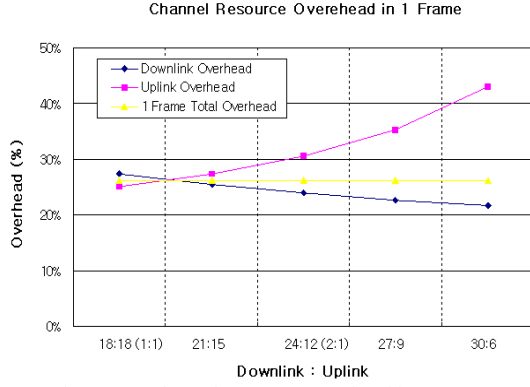


Figure 2. Channel Resource Overhead in 1 Frame

WiBro may not be compared directly with overhead channel power percentage of cdma2000 1X, overhead comparison of both systems gives an important inspiration for system efficiency because power in power-limited CDMA system means resource. Total 1 frame overhead is similar to the overhead channel power percentage of cdma2000 1X, 28.4 %, operated by SK Telecom.

IV. CAPACITY ANALYSIS

The radio link quality influences directly the available throughput. It is sure that the lower the radio link quality is, the lower throughput is allowed or possible. CINR (Carrier-to-Interference and Noise Ratio) represents the radio link quality, so it determines MCS (Modulation and Coding Scheme) level of channel. Capacity can be derived from the modulation type, code rate, a number of symbol, a number of sub-channel, and a number of sub-carrier allocated into a sub-channel. In this section we address the CINR calculation, the relation between capacity and coverage, and capacity with the PFRS(Proportional Fairness Rate Scheduler) algorithm.

A. CINR Calculation

The average CINR per a sub-channel is expressed as (2). I_{oc} is interference from the other cells in 2-tier cell structure environment i.e. 19 hexagonal cells.

$$CINR = \frac{1}{K} \sum_{k=1}^K \frac{1}{\alpha} \sum_{i=1}^{\alpha} \frac{P_c L_p G_b G_f}{I_{oc} + N_o W} \quad (2)$$

$$I_{oc} = \sum_{j=1}^J P_c L_j G_m G_f \beta_{ij}^k$$

where,

$$\left\{ \begin{array}{l} P_c : \text{power per a carrier} \\ K : \text{a number of sub-channel allocated into a cell} \\ \alpha : \text{a number of sub-carrier allocated into a sub-channel} \\ L_p : \text{radio propagation loss} \\ I_{oc} : \text{interference from the other cells} \\ N_o : \text{thermal noise density} \\ W : \text{system bandwidth} \\ G_b : \text{BTS Antenna Gain including cable loss} \\ G_f : \text{fade margin including shadowing} \end{array} \right\}$$

$$\left\{ \begin{array}{l} J : \text{a number of other cell, 18} \\ L_j : \text{radio propagation loss between target cell and other cell} \\ \beta_{ij}^k = \left\{ \begin{array}{l} 1 : \text{when } i\text{th sub-carrier of } k \text{ channel in target cell} \\ \text{is allocated in } j \text{ cell} \\ 0 : \text{else} \end{array} \right\} \end{array} \right\}$$

CINR calculation is performed in two environments: 19 omni cells and 57 sectors (in case, cell consists of 3 sectors). In order to get the average CINR, target cell is set up in center cell and 7 cells within 1-tier successively.

Fig. 3 represents downlink CINR profile in an omni cell of which coverage is 1km. Its channel conditions are ITU-R Veh-A and Ped-A. Fig. 4 shows downlink CINR profile in a sector. From these results we can see that the increased number of channel leads to low CINR. It results from the increased number of sub-carrier conflicting with other cell. Also, sector CINR is lower than omni cell CINR. It is due to the increased total interference from many other sectors.

From these CINR distributions we can derive the average throughput per cell/sector theoretically. But we will simulate the system capacity in various situations using CINR calculation equation in order to obtain more realistic results. These are described in the following C-section.

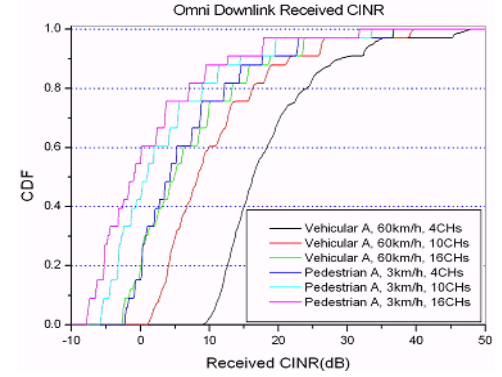


Figure 3. Downlink CINR Profile in Omni cell

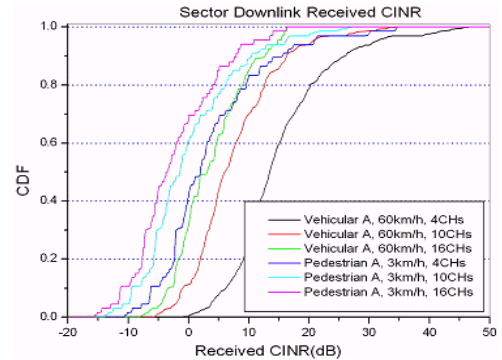


Figure 4. Downlink CINR Profile in sector

B. Capacity and Coverage

In this section we analyze the relation between capacity and coverage. It is assumed that user in target cell is located in cell edge. We perform the following 4 steps: 1) determine the modulation type and code rate, 2) calculate CINR in different cell radius, 3) allocate sub-channels to satisfy CINR value with PER(Packet Error Rate) 1%, 4) evaluate capacity from 1),2),3). Since a number of sub-channel has influence on CINR as a result of section A, a number of assigned sub-channel is limited.

Downlink has total 384 sub-channels. When we use QPSK with 1/12 code rate, 60 sub-channels can support 96 kbps and all downlink sub-channels support 614.4 kbps. But as CINR is lower in wider coverage edge, we cannot allocate all sub-channels to user. Therefore sector throughput of 1-user decreases. If we use 16 QAM with 1/2 and 64 QAM with 5/6, ideal sector throughput could be 7.4 Mbps and 18.4 Mbps, respectively. But we get the lower throughput: 1.8 Mbps and 4 Mbps due to limited sub-channels in Fig. 5.

Fig. 6 shows the uplink results which have the similar relation to Fig. 5. But we can find the interesting issue from Fig. 6(b), (c). Although 16 QAM with 2/3 code rate is supported in uplink, the use of QPSK with 1/2 code rate is more efficient in terms of sub-channel allocation limit considering CINR.

These results illustrate that as the site tries to cover more geographic area, a tradeoff is made in terms of throughput due to the lower modulation type employed. From fig. 5(a) we can see that coverage is limited to about 1 km for ITU Vehicular channel condition to meet that minimum downlink transmission data rate per user is 512 kbps.

C. Capacity analysis with scheduling algorithm

We simulate the performance of WiBro in 2-tier cell structure environment i.e. 19 cells, 3 sectors/cell. Simulation condition is that the proportion of downlink to uplink is 24 to 12 because of the reason described in section II and 5 types of radio environment are considered: ITU Veh-A 60 km/h, Ped-A 3 km/h, 10km/h, Ped-B 3 km/h, 10 km/h. Users are distributed uniformly in a sector. Each user experiences different path-loss, log-normal shadowing, and Rayleigh fading independently. Developed simulator adopt packet scheduling algorithm as PFRS. This algorithm assigns channel resource to user who has the maximum ratio of data rate requested by PSS to average throughput taken for typical period. Simulation is performed according to a number of users, the ratio of band selection channel to diversity channel, and other cell loading factor.

Fig. 7 shows the simulation results. Sector throughput for 20 users is higher than that for 10 users and is similar to that for 30 users. In general, sector throughput increases and then is saturated as user increases owing to the effect of PFRS. We think the proper number of user be 20 ~ 30 for WiBro from fig. 7(a), (b). Also, we can see the small variance of sector throughput according to the rate of channel mode. It is reasonable that we determine the rate of channel mode after analyzing user mobility pattern in the real market. Fig. 7(c) represents sector throughput according to other cell loading in case for 20 users. When the other cell loading becomes high, sector throughput become low because of the increased interference. In full loading, WiBro achieves 5.76 Mbps downlink sector throughput and 2.64 Mbps uplink sector throughput.

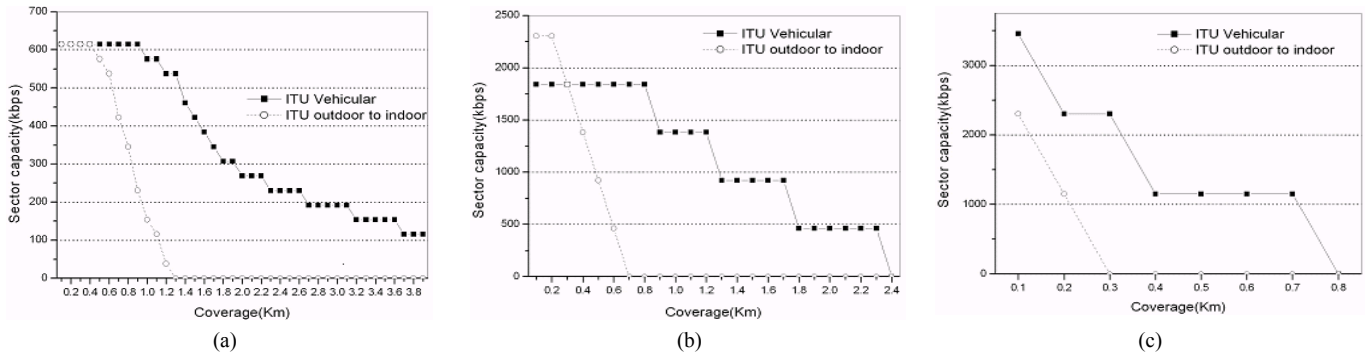


Figure 5. Downlink sector capacity analysis vs. coverage. (a) QPSK (1/12), (b) 16 QAM (1/2), (C) 64 QAM (5/6)

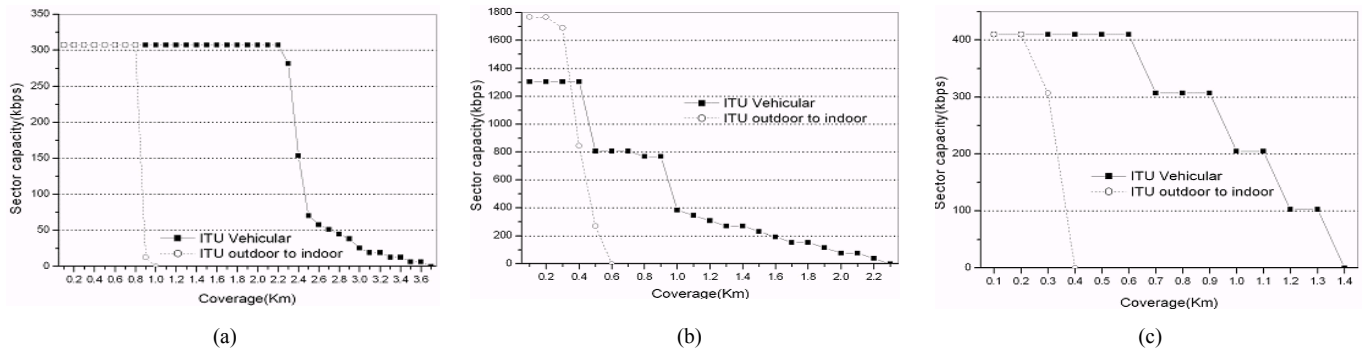
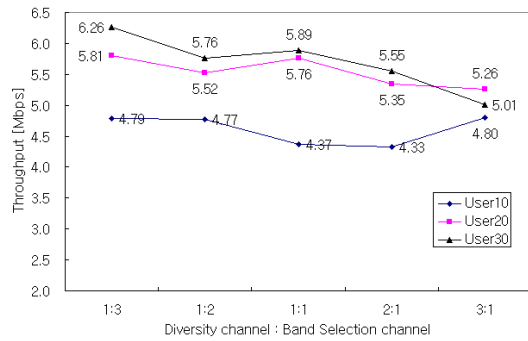
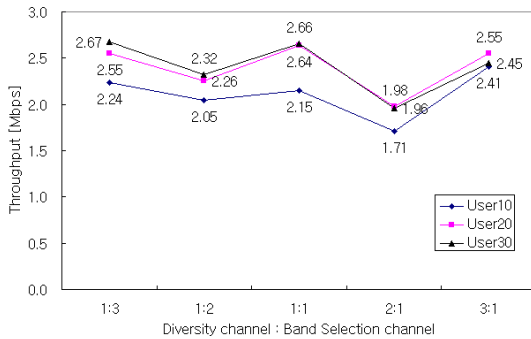


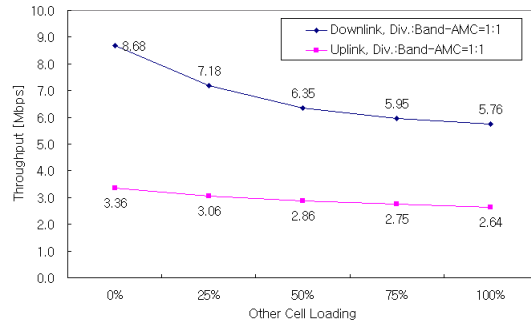
Figure 6. Uplink sector capacity analysis vs. coverage. (a) QPSK (1/12), (b) QPSK (1/2), (C) 16 QAM (2/3)



(a)



(b)



(c)

Figure 7. Sector capacity according to a number of user, the ratio of channel mode and other cell loading. (a) Downlink throughput, (b) Uplink throughput, (c) Sector capacity according to other cell loading

V. CONCLUSIONS

In this paper we analyze the performance of WiBro in the various network conditions. We show that the proper link proportion is 2 to 1 for DL to UL in consideration of both link overhead balance and asymmetric wireless data characteristics. It is illustrated that although the site tries to cover more geographic area, a tradeoff is made in terms of throughput due to the lower employed modulation type and also higher throughput is limited by a number of allocated sub-channels. Therefore the adequate coverage control and the allocation scheme of sub-channel for adopted MCS level are the important factors for optimizing the network operation. We can see that coverage is limited to about 1 km for ITU Vehicular channel condition to meet that minimum downlink

transmission data rate per user is 512 kbps. Also, simulation results indicate that WiBro has 5.76 Mbps downlink sector throughput and 2.64 Mbps uplink sector throughput when 20 users experiencing mixed 5 types of ratio environment are distributed uniformly in a sector and other cell loading is full.

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