Comparison of IEEE802.16 WiMax Scenarios with Fixed and Mobile Subscribers in Tight Reuse

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***Abstract* — WiMax broadband MAN based on the IEEE 802.16d/e standard supports mobile as well as fixed wireless access services. Both types of subscriber data links are characterized by totally different radio conditions such as e.g. propagation, interference rejection capability, terminal antenna gain, pattern and height. This leads to a significant coverage mismatch, different user application throughput and varying system capacity. Especially the mixture of both mobile and fixed subscribers sharing the same radio resources will consequently determine the cellular network structure, frequency planning and radio resource management. In this paper the performance of mobile and fixed WiMax data links in cellular 3.5 GHz deployments has been thoroughly analyzed depending on cell size, frequency reuse and system load. Detailed link and network level simulations have been provided for an OFDM-256 system with 3.5 MHz channels deployed in homogeneous hexagonal tight 1x1 and 1x3 reuse with cell radius of 300 m, 1000 m, and 2000 m. Simulation results for the user application throughput, modulation and coding scheme utilization, FTP download time, channel load and packet call blocking have been presented.**

Keywords - IEEE802.16, BWA, FWA, MAN, OFDM, Performance, WiMax.

I. INTRODUCTION

IEEE802.16 (WiMax) allows the deployment of cellular wireless metropolitan area networks (MAN) with non-line-of-sight (NLOS) radio conditions based on a new efficient OFDM air interface [1], [2]. The availability of a huge number of cost efficient equipment is the major advantage compared to existing proprietary wireless local loop (WLL) solutions. Various broadband applications and services have been envisaged such as WLAN feeding, wireless DSL and fast Internet access. Scenarios with an arbitrary mixture of mobile subscriber stations (MSS) enjoying WiMax services on their Laptop as well as residential stationary subscriber stations (SS) characterized by fixed installed customer premises equipment (CPE) are feasible. Interoperability is granted by certified standard compliant Laptop/PC cards and terminals. However, the data links of mobile and fixed wireless access subscribers significantly differ with respect to radio performance. The fixed wireless highly directive outdoor CPE antenna mounted closely to roof top ensures almost ideal propagation conditions by perfect alignment with the best serving base station (BS). The high antenna gain provides a good received signal level even for large cells while the directive antenna pattern ensures an excellent intra- and inter-site interference rejection especially in cellular network deployments with tight frequency reuse. In contrast mobile subscribers located closely to ground level are suffering from degraded radio conditions. Omni-directional antennae besides poor antenna gain do not provide any interference rejection capability resulting in a reduced coverage as well as in degraded C/I performance of MSS compared to SS. Obviously the network should be aware of the subscriber type to get most of the capacity benefit by appropriate network design, frequency planning and an advanced radio resource management.

Cellular interference limited deployments in dense urban environment with cell radius ranging from small 300 m up to large 2000 m have been analyzed for varying system load in the range from a rather unloaded to a fully loaded network for both MSS and SS scenarios. A single 3.5 MHz OFDM channel consisting of 256 sub-carriers has been allocated in the 3.5 GHz band in each cell. Due to assumed lack of spectrum/bandwidth the OFDM channels have been planned in tight 1x1 or 1x3 frequency reuse. Basic WiMax performance has been investigated, meaning that advanced as well as optional features in the IEEE802.16 standard promising significant performance improvements in the future have not been considered. In this study a decent fully standard compliant receiver performance of the subscriber stations (MSS and SS) has been assumed.

Detailed link level and system level simulation results have been provided showing the excellent performance of IEEE802.16 in cellular deployments. Wireless Internet access has been modeled as FTP download with a moderate file size.

The paper is structured as follows. Section II briefly describes the system level simulation environment, the scenarios under study and the relevant parameter settings. In Section III link level as well as system level simulation results on coverage, application throughput, modulation and coding scheme (MCS) distributions, data capacity and spectrum efficiency are presented for homogeneous hexagonal cellular network deployments in tight 1x1 and 1x3 reuse with site-to-site distance of 900 m, 3000 m, 6000 m under varying system load. Scenarios with both mobile and fixed subscribers have been investigated. The main conclusions are drawn in Section IV.

II. SIMULATION MODEL

To study the performance of a cellular IEEE802.16 (WiMax) OFDM-256 system in terms of user throughput (end-to-end application throughput), capacity and quality, system level simulations have been performed in 1x1 as well as in 1x3 frequency reuse depending on the offered cell load. Correspondingly a single channel (3.5 MHz) deployment scenario and a medium bandwidth scenario with 10.5 MHz spectrum availability in the 3.5 GHz frequency band have been assumed. In both cases this leads to a typical initial 1/1/1

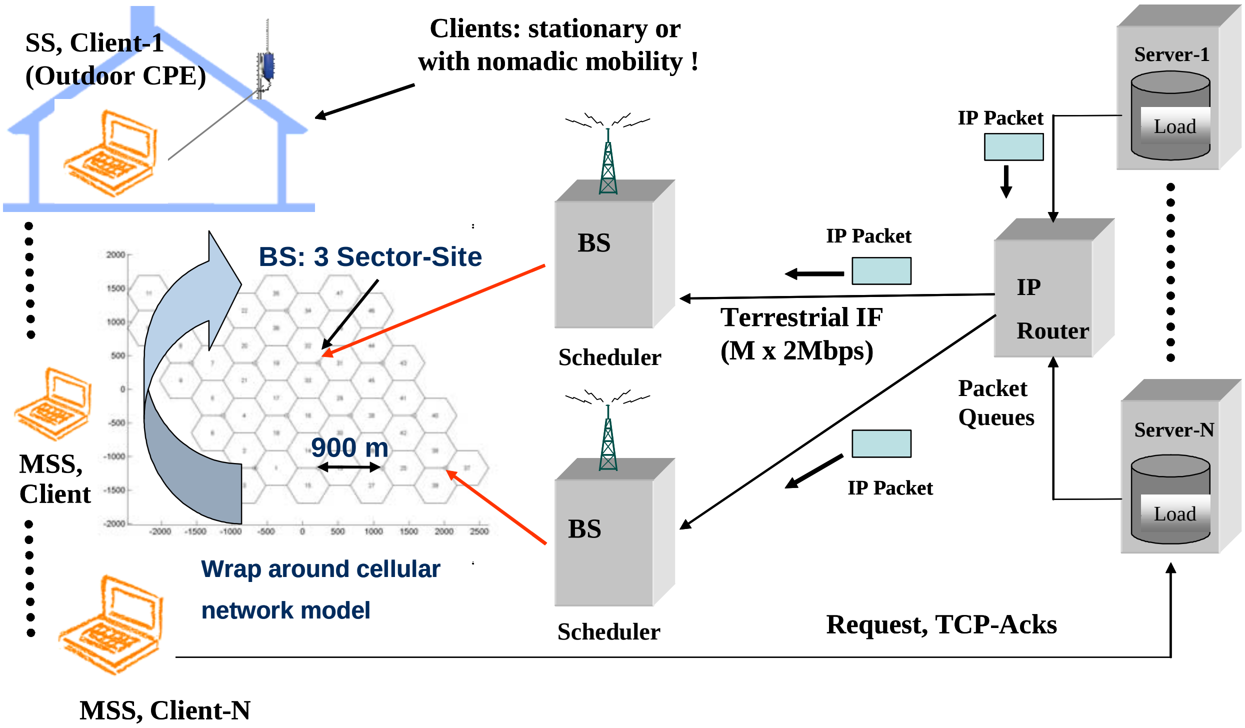

Fig. 1. IEEE802.16 (WiMax) OFDM System Level Simulation Model supporting both mobile subscribers (MSS) and fixed subscribers (SS).

configuration (i.e. 3-sectored sites with a single transceiver per sector). Table I gives an overview of the essential parameter settings used in the system simulation model presented in Fig.1.

TABLE I. ESSENTIAL PARAMETERS OF THE RADIO NETWORK MODEL

Parameter	Value
Number of sites	16 wrapped around on torus, 3 sectors per site
Site-to-site distance	900 m (300 m cell radius), 3000 m (1000 m cell radius) and 6000 m (2000 m cell radius)
Frequency reuse pattern	1x1 and 1x3
Available bandwidth	3.5 MHz in 1x1 reuse 10.5 MHz in 1x3 reuse
Frequency band	3.5 GHz
Subscriber distribution	uniform, random positioning for MSS and SS
Pathloss slope	37.6 dB per decade
Propagation Model	COST-231
BS transmit power (BS TXP)	2 Watt (33 dBm)
BS antenna	65°, 17.5 dBi, 35 m above ground, no down-tilt
MSS, SS: client antenna	MSS: Omni, 0 dBi, 1.5 m above ground SS: directive 20°, 17 dBi, 6 m above ground
Power control (PC)	Downlink PC switched off
Slow fading std. deviation	8 dB
Modulation and Coding Schemes (MCS)	BPSK ½, QPSK ½, …, 64-QAM ¾
Link Adaptation	Enabled, best throughput criterion
OFDM Symbol Duration	68 µs, 4 µs CP (cyclic prefix)
TDMA Frame	2 ms (30 OFDM symbols = 3 symbols overhead[a] + 27 symbols payload)
Scheduler	Cyclic on N x OFDM symbol basis (N x 68 µs), typically N = 1, 2, 3.

[a]Preamble, broadcast control and access definition (downlink/uplink maps)

A hexagonal cell layout consisting of 48 cells wrapped around on torus with a site-to-site distance of 900/3000/6000 m (300/1000/2000 m cell radius), a propagation index of 3.76 and a slow fading standard deviation of 8 dB have been used. A dense urban interference limited network deployment with up to 300 uniformly distributed MSS or SS clients per sector has been modeled. Mobile subscribers are assumed to enjoy portability and nomadic mobility. Hence during network access and data transfer MSS stay at the same position (stationary) and are always connected to the best serving BS. Correspondingly fixed subscribers have a directive high gain antenna perfectly aligned with the best serving BS. The radio interface supports full automatic Link Adaptation functionality with maximum throughput optimization. The BS transmit power is kept fixed at 2 W (33 dBm), downlink power control (PC) has been switched off. A typical point-to-multipoint fixed wireless access BS antenna with 65° beam-width and no down-tilt has been selected. Note that comparable conventional mobile network deployments also typically use a 65° antenna, however, with 4° to 6° down-tilt. A decent MSS / SS receiver performance fully compliant with the IEEE 802.16d specification has been assumed.

A cyclic MAC (Medium Access Control) scheduler is used operating on 1 to 3 OFDM symbol basis. Hence within a single 2 ms TDMA frame consisting of 30 OFDM symbols (3 overhead and 27 payload symbols) at least 27 / 3 = 9 subscribers can be multiplexed. The maximum number of users simultaneously multiplexed on the same OFDM channel has been limited to 30. A complete automatic repeat request (ARQ) functionality excluding hybrid ARQ has been implemented.

The terrestrial BS interface provides sufficient bandwidth to

avoid any degradation in terms of delay and throughput. Fifteen PCM 2 Mbps lines per BS have been configured (total of 30 Mbps) exceeding the BS air interface capacity roughly by a factor of three. The network layer comprises the transmission of IP packets as well as routing functionality. The transport layer offers both UDP as well as the complete TCP Reno implementation. Specific features of TCP have severe impact on the overall performance of wireless data services. Thus the model covers for example the choice of the maximum IP segment size, advertising window size of the receiver/client (AWND), the congestion window management at the sender/server and TCP slow start. The TCP roundtrip time (RTT) is continuously measured and filtered to update the retransmission timeout (RTO). RTO expiry causes TCP retransmissions and a new slow start. In addition the effects of duplicate acknowledgments (DUPACKs) combined with fast recovery and fast retransmit are part of the model.
The application layer consists of a variety of traffic models for WAP, HTTP, E-Mail, FTP, SMS, MMS and streaming services. In this study results for FTP 300 kByte download are presented. Note that in average all MSS/SS download the same busy hour data volume independent of location and radio link quality. Hence MSS/SS under poor radio conditions require significantly more time for the download of a 300 kByte file and thus occupy more channel resources than MSS/SS under good radio conditions due to the more robust MCS selected by LA and higher OFDM symbol error rate.

III. Link Level and System Level Simulation Results

A. 256 sub-carrier OFDM Link Level Performance

Fig. 2 shows the WiMax 256 sub-carrier OFDM Link Level performance in terms of user throughput vs. carrier to interference plus noise ratio C/(I+N) for a channel bandwidth of 3.5 MHz (192 sub-carriers payload, 55 guard, 8 pilots and zero carrier). A type 1 channel model (2 tap multipath model) according to [1] has been assumed. Seven different MCS ranging from BPSK ½ over 4-QAM ½ (equivalent to QPSK ½) up to 64-QAM ¾ have been presented. According to the IEEE 802.16 standard the BPSK coding consists of a convolutional coder only, whereas all other MCS are based on both Reed

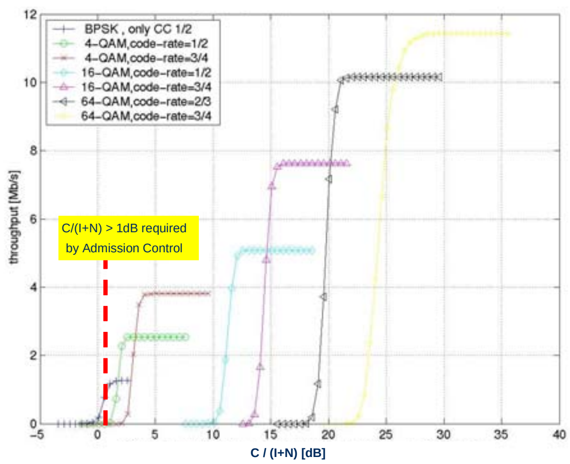

Fig. 2. Link level throughput vs. C/(I+N), 3.5 MHz OFDM channel.

Solomon and convolutional coding. Optional features such as turbo coding or low density parity check codes (LDPC) have not been considered.
The noise floor is calculated at *k.T.B.F = -101 dBm* taking into account a typical mobile receiver noise figure *F* of 7 dB.
For the type 1 channel the interference has been calculated for a single OFDM co-channel interferer 10 dB above noise floor of -101dBm. The wanted signal level C has been varied from -55 dBm down to -95 dBm. As expected usage of MCS 64-QAM ¾ requires a high C/(I+N) exceeding 25dB, however, achieving an excellent user throughput close to 27 / 30 * 864 bit / 68 µs = 11.5 Mbps. The most robust MCS BPSK ½ provides good user throughput beyond 1 Mbps even at a low C/(I+N) of 1 dB. Obviously a minimum C/(I+N) of 1 dB is necessary for a successful network access and stable data transfer with reasonable throughput. An Admission Control functionality implemented in the BS prevents both system overload and packet call blocking.

B. Propagation Model and Coverage

An UMTS 30.03 propagation model scaled to 3.5 GHz [3], [4] has been used. MSS and SS have a different unit pathloss corresponding to MSS omni-directional antennae located 1.5 m above ground and high gain directive SS antennae mounted 6.0 m above ground. Fig. 3 depicts the mean MSS and SS outdoor received signal level (RX Level) vs. range for a BS TXP of 2 W (33 dBm). Due to the pathloss difference of roughly 30 dB (mainly caused by the SS high gain CPE antenna) the MSS RX Level dives into the noise floor of –101 dBm already at roughly 3 km, the SS RX Level at roughly 23 km. Taking into account the effect of additional slow fading with 8 dB standard deviation the outdoor MSS range is limited to about 2.2 km, while the SS range is given by approximately 17 km at 90% cell area coverage (5.5 dB slow fading margin required). Note that the lack of sufficient MSS coverage strongly determines the overall radio network planning in mixed MSS and SS scenarios. Due to the weaker MSS link the maximum cell radius is limited to 1.1 km. The introduction of a hierarchical cell structure with MSS served by micro cells and SS served by macro cells might be a feasible alternative. Another option (depicted in Fig. 3) for reducing the coverage mismatch is to substantially increase the BS TXP for MSS links from 2 W to e.g. 30 W.

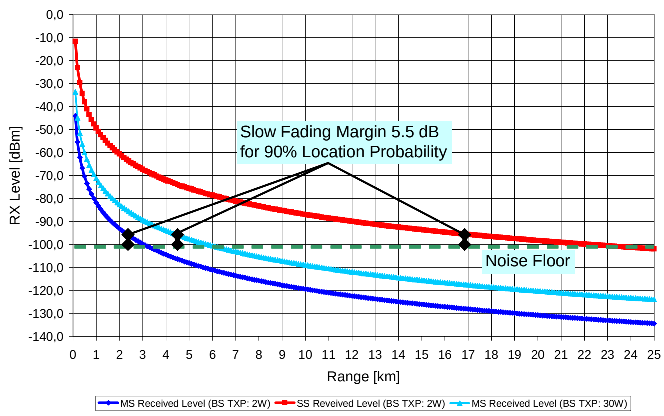

Fig. 3. Received signal level vs. range for MSS and SS.

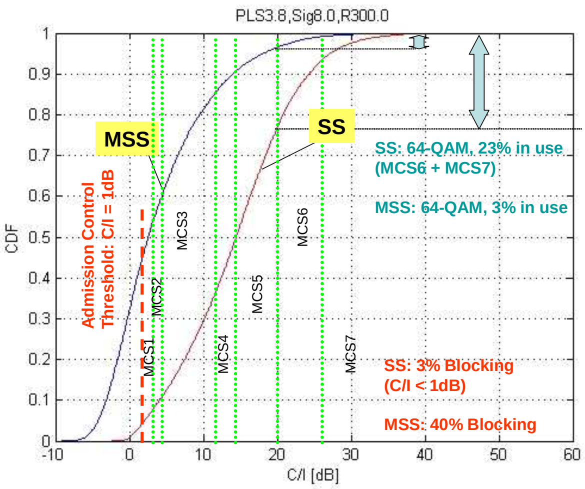

Fig. 4a. CDF of C/I and MCS utilization in 1x1 reuse at 100% system load.

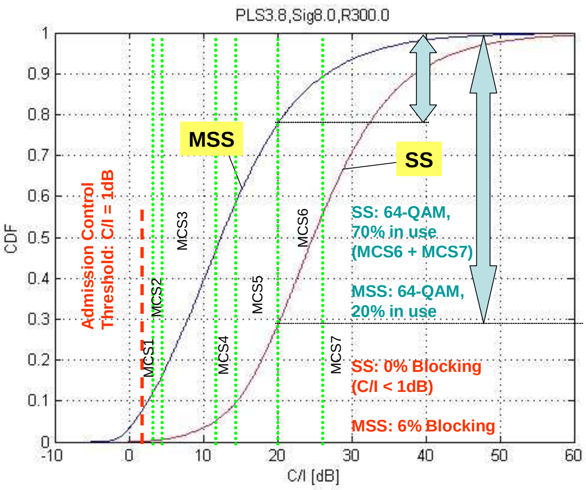

Fig. 4b. CDF of C/I and MCS utilization in 1x3 reuse at 100% system load.

C. *Graphical Performance Estimation*

Applying the methodology for rapid performance estimation proposed in [6] the performance of both MSS and SS has been evaluated in terms of MCS utilization in a fully loaded system with different frequency reuse schemes. This is accomplished by mapping the optimum switch-over points (between two MCS) in terms of C/I obtained by ideal LA from the throughput vs. C/I graphs in Fig. 2 onto the Cumulative Distribution Function (CDF) of the cell C/I measured in the network with the respective reuse scheme.

The results for a fully interference limited scenario (cell radius of 300 m corresponding to 600 m cell range assuring a wanted signal level more than 20 dB above noise level, ref. to Fig. 3) at 100% system load are presented in Fig. 4a for 1x1 reuse and in Fig. 4b for 1x3 reuse, respectively. In both reuse schemes the C/I experienced by SS exceeds the MSS C/I by more than 10 dB. The high gain directive SS antenna increases the received level and provides significant interference suppression by the antenna pattern thus resulting in a higher C/I compared to the omni-directional MSS antenna. Hence the portion of subscribers enjoying 64-QAM modulation with MCS_6 or MCS_7 is roughly 23% for SS vs. 3% for MSS in 1x1 reuse (see Fig. 4a), and about 70% for SS vs. 20% for MSS in 1x3 reuse (see Fig. 4b). The portion of subscribers with denied network access (call blocking) characterized by a C/I of less than 1 dB is roughly 40% for MSS vs. 3% for SS in 1x1 reuse and about 6% for MSS vs. 0% for SS in 1x3 reuse.

Obviously SS are expected to show acceptable performance both in 1x1 and 1x3 reuse independent of system load while MSS are only applicable in 1x3 reuse over the entire system load range. These rough estimates are confirmed by system level simulations in Section III G. Since a packet call blocking of 40% is unacceptable an appropriate Admission Control (AC) functionality on the network side is required to limit the system load in MSS scenarios in 1x1 frequency reuse.

D. *Application Throughput*

Fig. 5 presents the system level simulation results of the FTP 300 kByte end-to-end mean application throughput depending on the cell load for MSS and SS for a 3.5 MHz channel in 1x1 and 1x3 frequency reuse, respectively. The cell radius has been set to 300 m, 1000 m and 2000 m. SS outperform MSS in both reuse schemes over the entire system load range and show a behavior nearly independent of cell size.

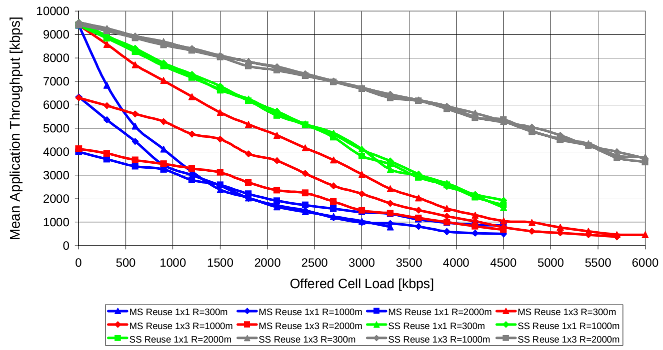

Fig. 5. FTP 300 kByte mean application throughput vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for MSS, SS and varying cell size.

For MSS 1x3 reuse seems to be more suitable than 1x1 reuse. However, independent of the reuse scheme MSS are dramatically affected by increasing cell size due to lack of coverage (cf. Fig. 3). The throughput degrades substantially for 1000 m and especially for 2000 m cells even at low system load. At a very low system load a mean application throughput of roughly 8-9 Mbps has been achieved with MSS in small cells only, while with SS this throughput is achieved for all studied cell sizes both in 1x1 and 1x3 reuse. As expected the throughput decreases in all scenarios with increasing cell load due to the growing inter-cell interference as well as resource sharing by multiplexing users on the same channel. Furthermore the channels planned in 1x3 reuse can be loaded significantly higher than in 1x1 reuse and provide better application throughput at equal cell load. Even at high system load a still respectable mean application throughput of 2-3 Mbps with MSS and even 3-4 Mbps with SS has been achieved.

E. *Download Time*

The mean download time for the FTP service with 300 kByte file size for MSS and SS is shown in Fig. 6 for both 1x1 and 1x3 frequency reuse depending on cell load and cell size.

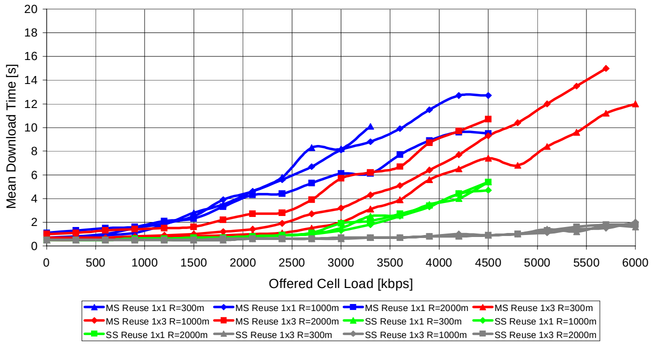

Fig. 6. FTP 300 kByte mean download time vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for MSS, SS and varying cell size.

At low system load the download time is below one second in all scenarios. Again frequency reuse 1x3 achieves a better performance than reuse 1x1 especially at medium to high cell load. In general SS significantly outperform MSS at the same cell load. MSS show a strong dependency on the cell range. Increasing cell load results in an exponential growth of the download time, which is mainly caused by the increasing number of multiplexed users sharing the same resource.

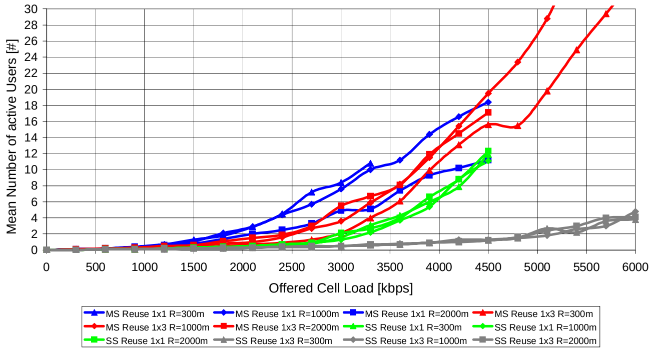

Fig. 7. Mean number of active MSS and SS users/sessions vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for MSS, SS and varying cell size.

The mean number of active users (active FTP sessions) vs. cell load is presented in Fig. 7. SS provide a superior throughput and require considerably shorter download time than MSS. Therefore SS need less channel resources, leave the system sooner and – as a consequence – less SS than MSS users are multiplexed on the same resource. The mean number of simultaneously multiplexed active WiMax users at a cell load (sector throughput) of even 4-5 Mbps on a single 3.5 MHz channel is well below 20.

F. Channel Utilization

As depicted in Fig. 8 the mean channel utilization (i.e. mean percentage of OFDM symbols carrying data payload) significantly differs in MSS and SS scenarios as well as between 1x1 and 1x3 frequency reuse at the same cell load. Note that an average channel utilization of 100% is almost impossible to achieve without totally overloading the system due to stochastic load fluctuations in the traffic model. In addition to protect the system from overload AC will limit the served traffic independently of the offered traffic. Therefore 100% average channel utilization can only be theoretically achieved. A linear extrapolation of the channel utilization towards 100% (cf. dashed lines in Fig. 8) results in a theoretically maximum achievable cell load providing an

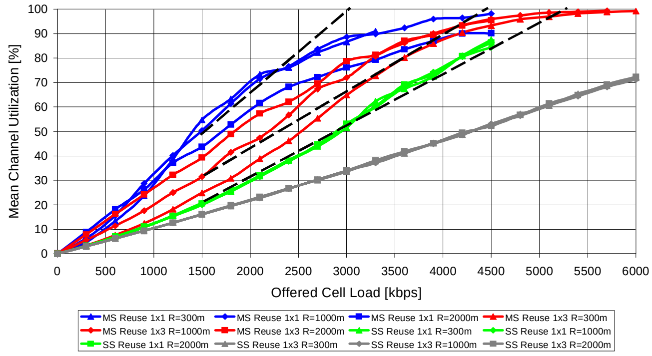

Fig. 8. Mean channel utilization vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for MSS, SS and varying cell size.

estimate for the spectrum efficiency η [bps/Hz/cell] of:

a. *(6.0 Mbps / 0.70) / (3 x 3.5 MHz)* = 0.82 for SS in 1x3 reuse,
b. *(3.5 Mbps / 0.80) / (3 x 3.5 MHz)* = 0.42 for MSS in 1x3 reuse,
c. *(4.5 Mbps / 0.85) / 3.5 MHz* = 1.51 for SS in 1/1 reuse,
d. *(2.0 Mbps / 0.70) / 3.5 MHz* = 0.82 for MSS in 1/1 reuse.

However, note that packet call blocking must be taken into account. Especially in the MSS 1x1 reuse scenario 100% channel utilization is not feasible due to unacceptable packet call blocking of 40% (cf. Fig. 4a and Fig. 10). In a real system the mean channel utilization should not exceed 70-80% in order to cope with large fluctuations in traffic model statistics, to ensure reasonable application throughput and especially to keep packet response times at an acceptable level.

G. Modulation and Coding Scheme Utilization

The portion of OFDM symbols utilizing 64-QAM (MCS_6 and MCS_7) vs. cell load has been compared in Fig. 9 for the MSS and the SS scenarios in 1x1 and 1x3 frequency reuse.

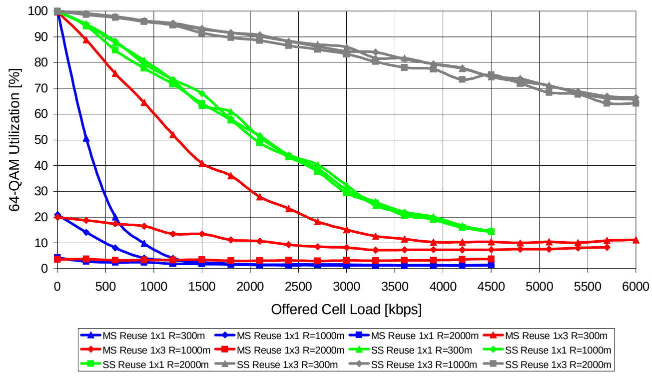

Fig. 9. QAM-64 utilization vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for MSS, SS and varying cell size.

The suggested figures in Section III C (Fig. 4) for 64-QAM utilization of roughly 23% for SS vs. 3% for MSS in 1x1 reuse and about 70% for SS vs. 20% for MSS in 1x3 reuse at full system load (300 m cells) are based on a traffic model with assumed fixed mean packet call duration. The system level simulation results based on a traffic model with fixed mean data volume (e.g. 300 kByte) in Fig. 9 show the same trend, however, as expected with slightly lower figures: 10% 64-QAM usage for SS vs. 2% for MSS in 1x1 reuse and 60% for SS vs. 10% for MSS in 1x3 reuse. A detailed explanation for this phenomenon can be found in [6]. In all cases the 64-QAM utilization decreases as the cell load increases due to growing interference level.

H. Packet Call Blocking

The link level performance in Fig. 2 suggests a minimum C/(I+N) of 1 dB for successful network access, otherwise the packet call is blocked. Fig. 10 depicts the packet call blocking for all investigated scenarios. MSS suffer from severe coverage problems in 2000 m cell deployments. Hence even at low system load a significant blocking of more than 20% is observed in both 1x1 and 1x3 reuse, which is totally unacceptable. By contrast SS blocking in 1x3 reuse has not been detected at all. In 1x1 reuse SS blocking approaches 3% at high system load.

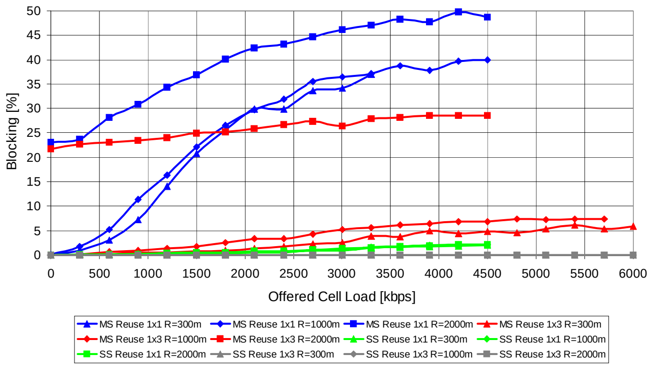

Fig. 10. MSS and SS packet call blocking vs. cell load for a 3.5 MHz channel in 1x1 and 1x3 reuse for varying cell size.

MSS in 1x3 reuse suffer from moderate 6% to 7% blocking at high system load in 300 m and 1000 m cells. For the same cell size in 1x1 reuse, however, MSS blocking dramatically increases towards 40% with increasing system load. An assumed acceptable blocking of e.g. 10% (corresponding to 90% cell coverage) is exceeded at about 1 Mbps cell load in 300 m cells substantially degrading the spectrum efficiency from η = 0.82 bps / Hz / cell as suggested in Section III F at 100% channel utilization down to η = 1.0 Mbps / 3.5 MHz = 0.29 bps / Hz / cell. As a matter of fact according to Fig. 8 the MSS channel utilization in 1x1 reuse must not exceed 30% (offered cell load of about 1 Mbps) to assure a maximum blocking of 10%. This is similar to the concept of fractional loading applied today in GSM/AMR networks in tight 1x1 frequency reuse [7]. It has to be pointed out, that WiMax could substantially benefit from an advanced receiver performance as well as capacity boosting features such as e.g. interference cancellation and/or smart antennas [8] shifting the feasible system load in 1x1 reuse far beyond 30%.

The blocking performance in Fig. 10 is fully in line with the graphical estimation provided in Section III C for both MSS and SS scenarios (cf. Fig. 4a and Fig. 4b). Obviously in cells with mixed MSS and SS subscribers at high system load the weaker MSS link might get into trouble especially due to lack of interference rejection of the omni-directional subscriber antenna.

IV. Conclusions

The basic IEEE802.16 (WiMax) 256 sub-carrier OFDM performance for a 3.5 MHz channel in the 3.5 GHz band has been analyzed by link and system level simulations in both interference and coverage limited cellular mobile environment. A detailed performance comparison between fixed (SS) and mobile (MSS) subscribers in two typical tight frequency reuse schemes (1x1 and 1x3) with varying cell size has been provided. In most scenarios WiMax offers an excellent end-to-end application throughput of several Mbps for SS as well as MSS. A cell throughput of e.g. 5 – 8 Mbps results in a site throughput of 15 – 24 Mbps, which has to be handled by the terrestrial transport. Fiber/STM1 or E3 lines might be required for each site. MSS and SS should be separated either on different TDMA frames (requires synchronized network) or on different frequencies. MSS and SS scenarios might have completely different system load, frequency reuse planning and also completely different coverage requirements. The MSS scenario works still fine for 1000 m cells, however, in 2000 m cells WiMax could not provide sufficient MSS coverage. It suffers from excessive and unacceptable blocking beyond 20%. Hence for MSS scenarios with large cells the BS transmit power should be significantly increased; 2 – 3 W are not sufficient. Very tight 1x1 reuse is best suited for SS providing the highest spectrum efficiency, while in tight 1x3 reuse only minor performance improvements are achieved at the expense of the spectrum efficiency. On the other hand 1x1 reuse is only partly appropriate for MSS and requires Admission Control functionality for a proper Quality of Service. MSS scenarios shall be deployed in 1x3 reuse in case of medium to high system load. SS take huge coverage and C/I benefits from the high gain directive CPE antenna. Especially MSS are affected by increasing cell size (e.g. 300 m => 1000 m) even at low system load and have to use more robust MCS. A large portion of MSS goes out of service in 2000 m cells. SS are nearly not affected at all even in 2000 m cells. Hence a combined MSS and SS deployment could profit from a hierarchical cell structure. To increase the spectrum efficiency advanced optional WiMax features have to be implemented.

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