Downlink Multi-user Transmission for Higher User Speeds in IEEE 802.16m

Christos Papathanasiou[1], Nikos Dimitriou[2], Leandros Tassiulas[1]
1. Institute of Accelerating Systems & Applications, University of Thessaly, Greece
2. Institute of Accelerating Systems & Applications, National & Kapodistrian University of Athens, Greece

Email: cpapa@uth.gr, nikodim@phys.uoa.gr, leandros@.uth.gr

Abstract—**A dynamic resource allocation algorithm with beam steering is evaluated for providing broadband wireless access to mobile users of the emerging IEEE 802.16m air interface standard. Thanks to our design, the coverage area and total throughput may be significantly enhanced, compared to the current IEEE 802.16e standard. Our proposed solution supports high mobility, improves fairness among the users and is backward compatible to the mobile networks based on the 802.16e. The simulation analysis determines the parameters which impact the system performance. Furthermore, our system presents low complexity hardware implementation and low power consumption.**

I. INTRODUCTION

Broadband Wireless Access (BWA) systems are rapidly growing as a next generation technology because they support high data rate transmission for demanding multimedia services. The existing global BWA standards are related to IEEE 802.16e, which support mobile wireless access (up to 120Km/h) [1]. The IEEE 802.16e standard is based on Orthogonal Frequency Division Multiplexing Access (OFDMA). The Multiple Input Multiple Output (MIMO) technique, by applying multiple antennas at the transmitter and receiver side, improves throughput in a rich scattering environment. In case of high user speeds, limited (and probably unreliable) channel knowledge is available at the Base Station (BS). Distributed sub-carrier allocation is the default configuration of IEEE 802.16e networks. It's distinguished between Full Usage of Sub-Channels (FUSC) and Partial Usage of Sub-Channels (PUSC). In FUSC, all sub-carriers are allocated in one cell or sector, while in PUSC only a set of sub-carriers is allocated to reduce interference with neighbour cells. These schemes provide good frequency diversity and perform well in mobility environments. Adaptive Modulation and Coding (AMC) permutation scheme enables a beamforming design and require the knowledge of Channel State Information (CSI) at the BS. AMC consists of adjacent tones and provide better protection against fading and interference but it's supported at low speed mobility classes from stationary to pedestrian.

The objective of this paper is to develop a novel technical solution for IEEE 802.16m networks [2]. IEEE 802.16m aims at defining an air interface that can support higher speeds with reasonable degradation, achieve higher spectral efficiency and significantly improve the coverage compared to the current 802.16e system, maintaining backward compatibility. The solution consists of joint beamforming, feedback design and scheduling in order to improve the system performance. These three mechanisms are closely coupled. The performance of the system depends on CSI that is provided through feedback as well as the on fading rate of each user. In a multi-user Time Division Duplexing (TDD) system, beamforming design could increases the capacity, assuming that the knowledge of CSI is available at the transmitter side. For higher mobility cases, the existence of a feedback delay from the user to the BS degrades the performance rapidly due to outdated and thus mismatched channel quality information. If the radio channel is varying fast, it can be easily understood that any kind of scheme that requires a small amount of channel feedback information will outperform a coherent beamforming scheme that requires the knowledge of the full instantaneous channel vector.

In [3], opportunistic beamforming artificially induces time fluctuations in the channel to increase the multi-user diversity. The overall system throughput is maximized by allocating the common channel resource to the user who can better exploit it. In this case, just a single user is scheduled at each time. Each user k feeds back the overall received Signal plus Noise Ratio (SNR) of its own channel to the BS. In reality, the statistics for the channel of different mobiles are not symmetric due to different distances from the BS, shadowing effects and scattering. It's possible that some mobiles have always better channel conditions than others. The scheduler may not schedule a particular user until its channel conditions are favourable. This causes increased scheduling latency or jitter for the user and leads to unfair resource allocation. One salient feature of IEEE 802.16e standard is the Quality of Service (QoS), which imposes stringent latency constraints. The scheduler may be forced to schedule the user even when the channel condition of the user is not favourable, which leads to limited multi-user diversity gain.

The scanned beams are formed without any knowledge about the position of the users. Therefore, channel quality feedback is not necessary for constructing beams (compared to the completely adaptive systems). Steerable beams provide a significant range extension and a considerable multipath and interference rejection. The BS schedules data transmission by exploiting

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limited feedback on the minimum SNR subcarrier per user. Predicting the SNR in the BS appears to be a challenging task. The necessary number of predictor coefficients is relatively high. In the IEEE 802.16e standard, a large number of sub-carriers (e.g. 2048 or 1024) are usually used. In order to reduce the amount of feedback, we use the feedback scheme proposed in [4]. N sub-carriers are divided into Q clusters of R sub-carriers each so that $N = QR$. For low speed mobility users, the channel varies slowly. A large number of clusters is selected to achieve optimum performance. At high user speeds, only a representative SNR is sent back because the fast variations of the channel make the large amount of feedback scheme obsolete and yield a mismatch between estimated and instantaneous channel. The efficiency of the proposed solution is studied by simulations with WINNER II channel model [5]. This simulation includes all the main propagation effects such path loss, shadowing, delay spread, angular spreads, spatial correlation, Doppler effects and so on.

This paper is structured as follows. The beamforming pattern is presented in section II. The combining technique at the receiver is explained in section III. Section IV introduces feedback schemes. In Section V, the scheduling strategy is described. Section VI presents simulation results, while conclusions are drawn in section VII.

II. BEAMFORMING PATTERN

Let's $h_k(t)$ be the channel matrix M_t x 1 of user k and w the beamforming vector M_t x 1 applying at the BS with M_t antenna elements. User k will experience a channel response characterized by

$$h_k^{eff}(t) = h_k^*(t)w(t) \quad (1)$$

The magnitude of the composite channel response $\left|h_k^{eff}(t)\right|$ is maximized when antenna gain is aligned to the optimum value

$$w_k^{opt} = \frac{h_k(t)}{||h_k(t)||} \quad (2)$$

It's difficult for the mobile to feedback the optimal gain at each sub-carrier due to large amount of feedback information this requires. In opportunistic beamforming the BS simply varies the antenna gain $w(t)$ and the mobile report their resulting time-varying SNRs. A mobile will experience a relatively high SNR when the randomly varying antenna gain happens to align closely to the optimal beamforming gain for the user. In order to solve the problem of scheduling latency, we align as much as possible the optimal beamforming gain for all users by scanning narrow wide beams not randomly but linearly from direction 0° to $\varphi_{\max}$ to cover all the area of interest. We schedule all the users, not only the users with high SNR.

Consider that the BWA system contains a sectorized cell grid. Each cell consists of four sector areas $S_j, \quad j \in \{1, 2, 3, 4\}$. One fourth of the available bandwidth is allocated to each sector. The sector area S_j is divided into N_B sub-areas of equal size ΔS (a grid of N_B beams). A narrow width beam is rotated to scan the whole area $S_j = \frac{360^o}{4} = 90^o$. A conventional beamformer is a simple beamformer with all its weights of equal magnitudes. The phases are selected to steer the antenna array in a particular direction ϕ_0, known as the look direction. Beamforming remains constant during each mini-slot m which is the scheduling time interval. The array weights for direction of main lobe ϕ_{0j} in area S_j is given by

$$w_{\phi_{0j}} = \frac{1}{\sqrt{M_t}} \left[1, e^{i2\pi d/\lambda \sin\phi_{0j}}, \cdots, e^{i2\pi(M_t-1)d/\lambda \sin\phi_{0j}}\right] \quad (3)$$

where d is the distance between adjacent antenna elements in a Uniform Linear Array (ULA) and λ is the carrier wavelength. The angle of steering beam ϕ_{0j} increases linearly in time

$$\phi_{0j}(t) = \phi_{init,j} + \Delta\phi \ t \quad t = 1, 2, \cdots, N_T \quad (4)$$

$\phi_{init,j} \in \{0^o, 90^o, 180^o, 270^o\}$ is the initial value of ϕ_{0j} and depend on sector area S_j that will be scanned, $\Delta\phi$ is the angle increment and N_T the period of beamforming process.

In a metropolitan area, no complete Line Of Sight (LOS) propagation exists between the BS and the vehicle. BS is mounted above rooftops to reduce near field scattering. The LOS path is attenuated due to appearance of diffraction at the first obstacle. The reflected signals, originated from local scatters near to the mobile, are received at a comparable power level to the attenuated direct path signal. If transmission occurs at one desired direction, multi-path power can be collected by users which are located at different directions. Therefore, the period of scanning can significantly be reduced. Furthermore, one user can be allocated to more than one steering beams during one period of scanning. Consequently, data latency could be reduced. Scanning methods use electronically steerable array antennas in order to cover the surrounding area. Each sector with 90° or 120° angular width can be served from 4 to 8 narrow beams. Two different approaches based on fixed phase shifting network are proposed. a) Blass matrix (series feed) where directional couplers and transmission lines are used to provide the necessary phase shifts and b) Butler matrix (parallel feed) , where 90° hybrids are interconnected by rows of fixed phase shifters to form the beam pattern. The above scanning methods don't require complex algorithms for beam selection and provide less cost and complexity. Integration into existing BWA systems is easy and cheap. Additionally, the proposed solution provides low power consumption since it doesn't require much signal processing for controlling the fixed beams and low loss passive components are used at the front-end.

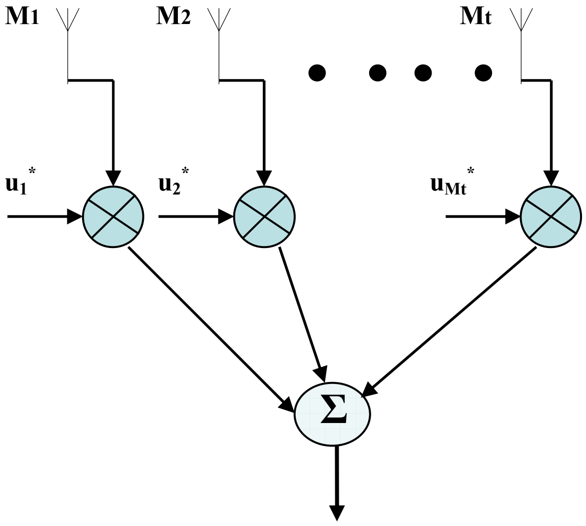

Figure 1. Combining strategy

III. COMBINING TECHNIQUE AT THE RECEIVER

In general, the requirement for compact mobile terminals severely limits the number of antennas that can be implemented. In our design, signals received from two or four antenna elements of each mobile ($M_r = 2$ or $M_r = 4$) are linearly combined to improve the SNR. Remember that the BS schedules data transmission by exploiting limited feedback on the minimum SNR subcarrier. We suppose that CSI is known at the receiver. The received signals are multiplied by a coefficient vector $U = [u_1, u_2, \cdots, u_{M_r}]$ before they are combined as in fig. 1. In [6], it is shown that Optimum Combiner (OC) and Maximum Ratio Combiner (MRC) techniques outperform the Antenna Selection (AS), when a limited number of users is served in an opportunistic scheme. Therefore, we choose MRC scheme to obtain the maximum SNR. The SNR computing at the receiver $k \in S_j$ for sub-carrier l is

$$SNR_{jkl} = \frac{\left|U_{kl}^H H_{kl} w_{\phi_{0j}}\right|^2}{\left\|U_{kl}\right\|^2 \ \sigma_k^2} \qquad (5)$$

with H_k the channel matrix M_r x M_t estimated at the receiver k and U_k the corresponding received vector. We suppose that the noise at the receiver is Gaussian with zero mean and variance σ_k^2 . In the MRC method, the antenna is aligned to the direction of $H_{kl} w_{\phi_{0j}}$.

IV. SNR FEEDBACK

The most important feature of OFDMA is its capability of exploiting the multi-user diversity in order to increase system throughput. Since large numbers of sub-carriers are usually used, feeding back CSI at the BS is prohibitive. To reduce the amount of feedback from the users to the BS, we divide the N sub-carriers into Q clusters of R sub-carriers each. For cluster c, the minimum SNR per cluster is fed back,

$$SNR_{jkc}^{min} = \min_{\{l\in\{m,m+1,\cdots,n\}\}} \{SNR_{jkl}\} \qquad (8)$$

We suppose that the first sub-carrier of cluster c is m and the last is n. Having large clusters, we reduce feedback but we support rates lower than optimum. In the simulations a suitable cluster size Q will be identified. Intuitively, if the channel coherence bandwidth is of the same order with the bandwidth occupied by the cluster c for appropriate number of sub-carriers per cluster R, the degradation on throughput should be very small.

The transmission can be organized in the following way: for TDD mode, the frame has duration 5ms and it is divided into N_B Downlink (DL) and N_B Uplink (UL) slots. As mentioned before, N_B = 4, 6 or 8. The slot is the unit at which scheduler can allocate data to each user. The DL slots always precede the UL slots and they are weighted by a linear rotated vector $w_{\phi_{0j}}$.The steered vector remains constant throughout the frame. Each DL slot starts with a preamble (one symbol long at each sub-carrier) for synchronization and identification purposes. Then each mobile calculates a representative $SNR_{j,k,c}^{min}$ for all clusters c. The user k sends back this channel information at the UL slot related to fixed beam $\phi_{0j}(t)$. A guard interval is introduced when the direction of

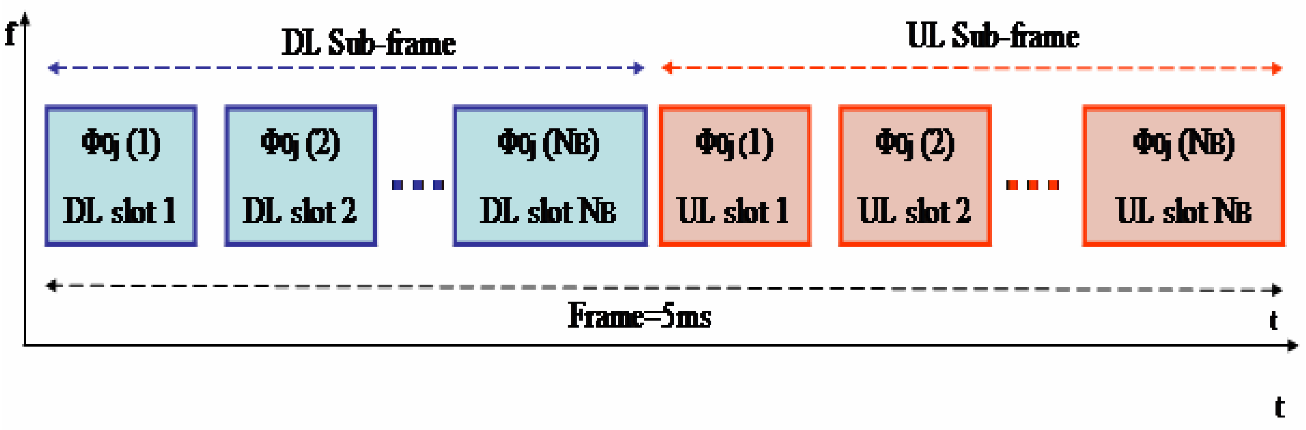

Figure 2. MAC frame structure

the beam changes. The BS transmits data at the next DL slot related to beam vector $w_{\phi_{0j}}$ only to users that send $SNR^{min}_{j,k,c}$ feedback information. The BS doesn't make predictions for SNR on all the tones of each clusters but makes the scheduling according to representative minimum value of SNR A diagram of the frame structure is shown in fig. 2.

V. SCHEDULING

The cluster allocation scheme subdivides the total bandwidth into Q clusters of R adjacent sub-carriers each. Our scheduling strategy is described as following:

1. Each user k feeds back information to the BS at each direction of the beam $\phi_{0j}(t)$ with $t = 1, 2, \cdots, N_B$. The mobile users with high velocity send $SNR^{min}_{j,k,c=1}$ as information for channel state, which correspond to the minimum SNR of all sub-carriers ($Q_{highspeed} = 1$). On the other hand, pedestrian or vehicular users send more load information during c frames, e.g SNR^{min}_{jkc}, $c = 1, 2, \cdots, Q$ ($Q_{pedestrian} > Q_{vehicular} > Q_{highspeed}$). We note that $Q_{pedestrian}$ is an integral manifold of $Q_{vehicular}$.

2. The BS constructs a set $\mathcal{C}_k$ of users having feedback information.

3. The number $\#\mathcal{C}_k$ of users which should be allocated is computed.

4. The number of sub-carriers that correspond to each user at each cluster c is $n_{c,k} = \lfloor \frac{R_{pedestrian}}{\#C_k} \rfloor$, where $\lfloor x \rfloor$ denotes the smallest integer that not exceeds x.

5. If $Q_{pedestrian} = \mu\ Q_{vehicular}$ with μ integer, the information of one vehicular user SNR^{min}_{jkc} is used at μ of $Q_{pedestrian}$ clusters, while the information of high speed users is used at all clusters. The order of allocation is random, because feedback information corresponds to the minimum SNR of each cluster.

6. If $\sum_{k=1}^{\#C_k} n_{c,k} < R_{pedestrian}$, we add the remainder of sub-carriers to stationary users in order to achieve maximum total system throughput.

VI. PERFORMANCE EVALUATION

This study focuses on the performance for the downlink direction. The system specifications of IEEE 802.16e are considered. The main system parameters are given in table I. The simulation scenario I includes a cell with one BS and 30 mobiles pseudo randomly located. All resources are utilized in each cell. Uniform Linear Arrays (ULA) with half wavelength spacing are used at both ends. The modulation and coding rates are selected according Table II which is compliant to IEEE 802.16e standard. The C1 metropolitan area for suburban macro-cell from WINNER II channel model is used. Path loss and shadow fading (Large Scale parameters) for LOS/NLOS case are selected. Our system is based on OFDM modulation. Consequently, we sum the signals seen at the receiver from different taps. This assumption is valid only for narrowband systems, as in OFDM systems.

TABLE I. SYSTEM MODEL PARAMETERS

Parameter	**Value**
Cell Radius (m)	3300
Frequency Band (GHz)	5.25
Number of BS array antenna elements	4
Number of MS array antenna elements	4
Mobile Velocity (Km/h)	110
Channel Bandwidth (MHz)	10
Frame Duration (ms)	5
OFDM Symbol Duration (µs)	102.86
Number of Data Subcarriers	800
BS Transmit Power (mW)	250
Channel Profile	WINNER II C1 Metropolitan
Mobile Station Distribution	Uniform, random positioning, 30 users per cell
Traffic Model	Full Buffer

In simulation scenario II, one MS moves across a circular path with radius R=1Km. The region of interest is scanned by three beams with steering directions 20°,0° and 340°. The average SNR versus azimuth for scenario II is shown in fig. 3. We note that all transmit beam patterns are symmetrical to the vertical axis due to the inherent radiation symmetry of the ULA. All users' SNRs range from 12 to 15 dB. Fig. 4 shows the average physical layer data as a function of distance. In the worst case scenario III, one user moves along the horizontal axis. In the best case scenario IV with three users, the first user moves along the horizontal axis, the second along the positive vertical axis and the third along the negative vertical axis. Our scheme for scenario IV achieves a 55% improvement over the whole range (minimum data rate 1Mbits/s) compared to the SIMO

1x4 configuration with 0dBi omni BS antenna. The users are equaled by the BS. In order to obtain also deep fades in the simulated channel profiles, we set in the WINNER II channel model the parameter 'sample Density' equal to 64, which means that 128 channel samples per wavelength are taken. The total number of time samples is 1000. The output of the channel is in the time domain. The frequency domain output is taken by applying the FFT algorithm. The maximum frequency depends on the number of samples. We obtain the bandwidth of 10 MHz by applying zero order hold interpolation with oversampling factor 198. We don't take double-sided spectrum because it is symmetric to the central frequency of operation f_c=5.25 GHz. Therefore, we double the power of each frequency component. After oversampling, we have 990000 points at the frequency axis. The cell throughput obtained at scenario I is illustrated in fig. 5 for different number of users (cell load). The feedback contains information of 20 clusters. Our scheduling strategy is compared to FUSC. FUSC doesn't need feedback information. Cell throughput can be improved by around 350% when using our proposed scheme instead of using omni directional antenna at the BS and FUSC with ½ coding rate and BPSK modulation type. In fig. 5, system throughput depends on position of users which are randomly distributed. Fig. 6 shows the total cell throughput for different amounts of feedback. The system capacity can be significantly enhanced with the feedback scheme, e.g. the cell throughput is improved from 1.25 Mbits/s to more than 2.5 Mbits/s if only the minimum SNR from all subcarriers are sent at the receiver and to more than 4 Mbits/s if 400 subcarriers are divided into 20 clusters and the minimum SNR of these 20 clusters are send back as feedback. The simulation shows that the number of scanning beams doesn't influence the system throughput. We have examined three possible cases. The first where the interested region is scanned by three beams with direction 320°,0°, and 20°, the second by four beams with direction 20°, 10°, 350°,340° and the third by five beams where we scan from 340° to 20° with step 10°. Additionally, we studied the effect of feedback delay by calculating the throughput per user for six users in scenario I. Fig. 7 plots the degradation of the throughput per user in case of ideal feedback delay, (δ=0ms), one frame (δ=5ms) and two frames (δ=10ms) delayed feedback information. In the worst case, a 10ms delay causes a throughput degradation per user of 10%, while a 5ms delay doesn't change the user rate. Finally, it can be seen in fig. 8 that the fairness is improved among the users in the scanning scheme compared to the omnidirectional case. In the latter scheme, a 30% of users don't achieve throughput while in the former scheme only 8% of the users don't establish connection.

VII. CONCLUSION

In this work, we have investigated a multi-user downlink transmission strategy that refers to beam-steering method, feedback design and scheduling for improving performance of 802.16e links in the context of communication between high speed vehicles and BS. It was shown that our scheme significantly enhances the coverage area, the overall system throughput and fairness among the users. The simulation results show that the total throughput doesn't increase proportionally to the number of clusters and is approximately constant if the number of fixed beams, that are scanned in each sector, is greater than a minimum value. Finally, the system throughput is independent of the cell load.

REFERENCES

[1] IEEE standard 802.16e-2005, "Air interface for fixed broadband wireless access systems",Feb. 2006.

[2] IEEE 802.16 Broadband Wireless Access Working Group, ' IEEE 802.16m System Requirements',2007-10-19.

[3] P. Viswanath, D. Tse, R. Larroia, "Oportunistic Beamforming Using Dump Antennas", IEEE Transactions on Information Theory, Vol. 48,No 6, June 2002.

[4] P. Svedman, S. K. Wilson, J. Cimimi, B. Ottersten, " A simplified Opportunistic Feedback and Scheduling Scheme for OFDM", Proceeding IEEE VTC spring, May 2004.

[5] IST-4-027756 WINNER II, D.1.1.2 WINNER II Channel Models. Part I Channel Models and Part II Channel Measurement and Analysis Results.

[6] R. Bosisio, U. Spagnolini, "On the Sum-Rate of Opportunistic Beamforming schemes with Multiple Antennas at the Receiver", ICC 07.

TABLE II. TYPE OF MODULATION AND CODING RATE ACCORDING TO SNR

Modulation	Coding	SNR (dB)
BPSK	1/2	3
QPSK	1/2	6
QPSK	3/4	8.5
16 QAM	1/2	11.5
16 QAM	3/4	15
64 QAM	2/3	19
64 QAM	3/4	21

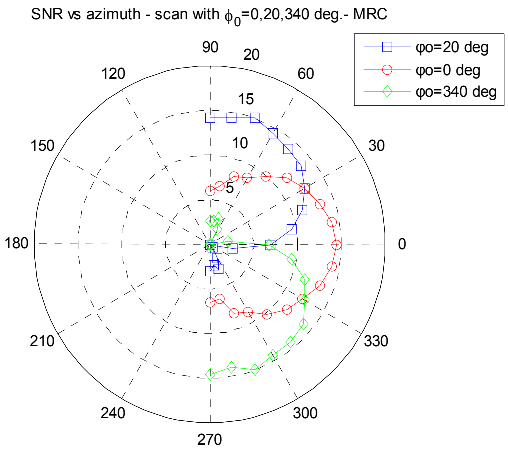

Figure 3. SNR versus azimuth

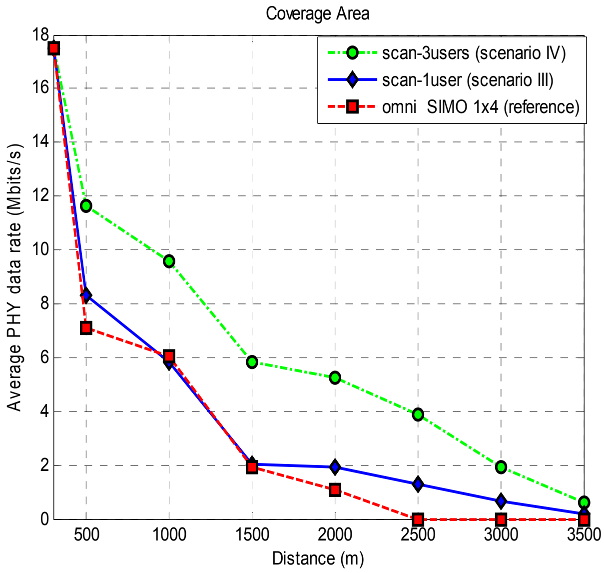

Figure 4. PHY data rate versus distance

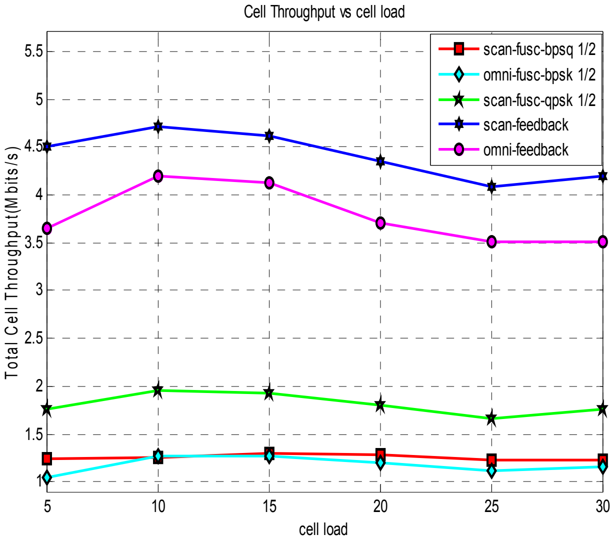

Figure 5. Total cell throughput versus cell load

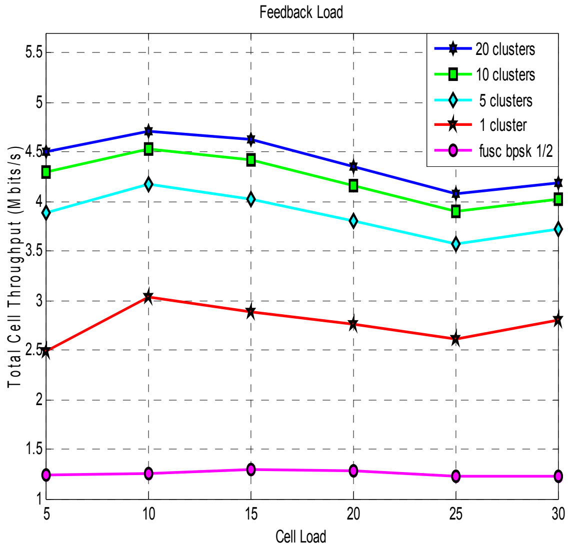

Figure 6. Total cell throughput versus feedback load

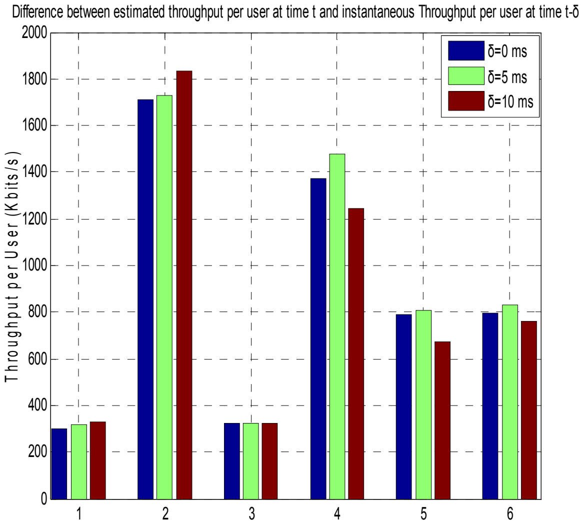

Figure 7. Difference between estimated throughput per user at time t and instaneous throughput per user at tim t-δ

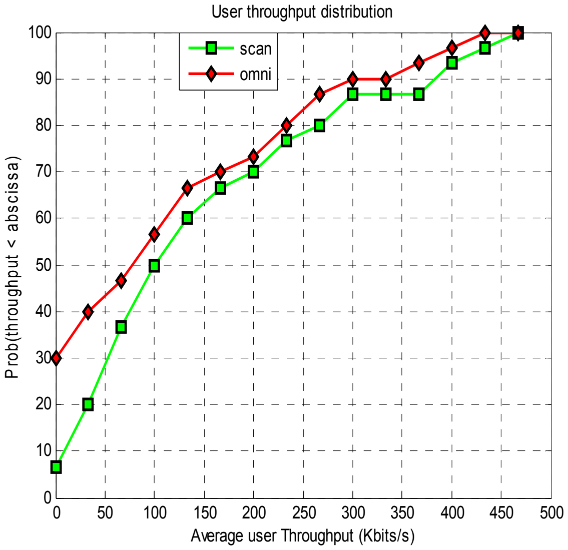

Figure 8. User throughput distribution