Relay Implementation in WiMAX System Level Simulator

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Abstract. Future wireless communication systems are expected to provide more stable and higher data rate transmissions in the whole network. WiMAX is one of the technologies to cover diverse geographic regions. WiMAX covers the high dense urban areas and provide access over large geographic regions in remote rural area. However, in both scenarios it is challenging to cover the entire service area. In both cases relays are foreseen to extend the range of the BS and to increase the system throughput allowing for a cost-efficient deployment and service. As multi-hop/relay has complex interactions between the routing and medium access control decisions, the extent to which analytical expressions can be used to explore its benefits are limited. Consequently simulations tend to be the preferred way of assessing the performance of relays. In this paper, we explain, how to deploy fixed-relays by using computer simulation in WiMAX system and we consistently observed that the throughput is increased and the outage is decreased in the relay-augmented WiMAX network, which is converted to range extension without any capacity penalty, for the realistic range of values of the propagation and other system parameters investigated.

Keywords: WiMax, Fixed Relay, Throughput, Coverage area.

1   Introduction

The current deployment of WiMAX 802.16e networks exhibits certain inherent problems in practice, such as low signal-to-noise-ratio (SNR) at the cell edge, coverage holes that exist due to shadowing and non-line-of-sight (NLOS) connections, the access requirement of non-uniform distributed traffic in densely populated areas (hotspots). Techniques such as MIMO (Multiple Input Multiple Output) are currently being investigated in WiMAX to provide increase in data rates. However, the MIMO applicability in cellular systems may only be limited to 2x2 configuration (2 transmit and 2 receive antennas) due to complexity concerns in the mobile terminal and the base station. This means that a theoretical maximum of 2 times improvement in data rate can be achieved by using spatial division multiplexing (SDM) in a 2x2 MIMO system.

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Another option is to use higher order modulations such as 64-QAM and 256-QAM etc. However, the applicability of higher order modulations in a mobile environment is an open issue due to concerns on channel estimation etc. As higher data rates typically use higher order modulation schemes which in turn require higher signal-to-interference and noise ratios (SINRs), we tend to be constrained only to service users close to the base station. These users will have favorable propagation characteristics, i.e. low path loss (PL) and interference. This suggests that we will either have to deploy more base stations to provide comparable coverage to that achieved for voice only services, or exploit a method which extends the range at which high SINRs can be achieved. The prohibitively large costs associated with the first option means that there is currently a lot of interest in industry and academia addressing the second. One of the most promising techniques that can extend the range at which a minimum SINR can be supported, is multi-hop, a technique originally proposed in [1]. Multi-hop uses either fixed seeds, i.e. Fixed relays, or the mobile relays, they are best considered via simulation rather than analytical means. The relay based architecture in WiMAX system promises to fully or partly solves the above mentioned problems faced with the centralized cellular architecture. In this paper we only consider the fixed relays. In order to meet the growing demand and stringent design requirements for coverage extension, throughput and capacity enhancement, deploying relay stations has been considered as a promising solution to IEEE 802.16[3] Point to-Multi-Point (PMP) networks, which are thus amended in standardization process of IEEE 802.16j[4].

In this paper we presents how to deploy fixed relay in WiMAX system which increase the system throughput and extension without any capacity penalty. The rest of paper is organized as follows. Section I discusses the characteristics of Relay station, Section II explains the system model for our simulation and section III shows the simulation results followed by the conclusion.

2   Characteristics of the Relay

Relaying is widely acknowledged as a means to improve capacity and coverage in Wireless Broadband Networks, see [5].The properties of our relay concept and the benefits that can be expected are as follows:

Radio Coverage can be improved in scenarios with high shadowing (e.g. bad urban or indoor scenarios). This allows to significantly increase the Quality of Service (QoS) of users in areas heavily shadowed from Base Station (BS).

The extension of the radio range of BS by means of Fixed Relay allows to operate much larger cells with broadband radio coverage than with a conventional one-hop system, while at the same time.

Reducing transmission power levels: In the case of the BS and relay stations, this will contribute to the public acceptance of such systems, while in the case of the mobile terminals it has the potential to increase battery lifetime.

The Fixed Relay concept provides the *possibility of installing temporary coverage* in areas where permanent coverage is not needed (e.g. construction sites, conference-/meeting-rooms) or where a *fast initial network roll-out* has to be performed.

The wireless connection of the Fixed Relay to the fixed network *substantially reduces infrastructure costs*, which in most cases are the dominant part of the roll-out and operations costs. Fixed Relay only need mains supply. In cases where no mains is available, relays could rely on solar power supply.

A *standard-conformant integration of the relays into any MAC frame based system* would allow for a stepwise enhancement of the coverage region of an already installed system. Investments in new BS can be saved and any hardware product complying to a wireless MAC frame based standard is possible to be used without modifications.

3   System Model Architecture

Orthogonal frequency division multiplexing (OFDM) is a transmission technique that is built-up by many orthogonal carriers that transmits simultaneously. The main idea behind OFDM is that a signal with a long symbol duration time is less sensitive to multipath fading, and narrow band co-channel interference, makes it possible to achieve even better system spectral efficiency than a signal with a short symbol time. Hence, a gain in performance can be achieved by sending several parallel symbols with a long symbol time than sending them in a series with a shorter symbol time. OFDMA (Orthogonal Frequency Division Multiple access) is the multi user version of the OFDM digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users. Products that use OFDMA are for example 3GPP Long Term Evolution, WiMAX etc.
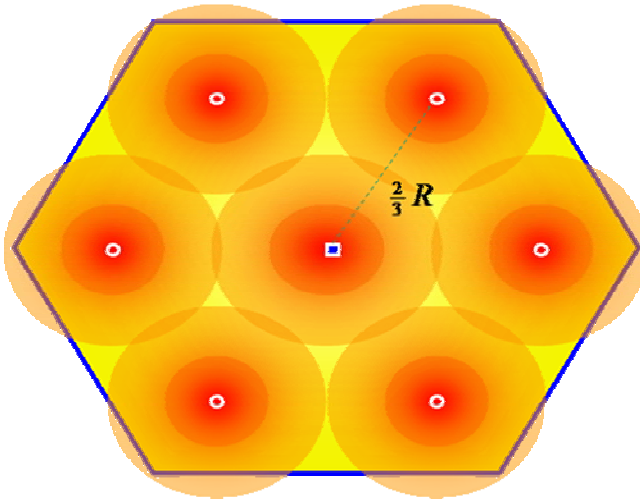
3.1   Cellular Layout

A network of seven clusters with four hexagonal cells in each cluster is considered in this paper. Similar to current cellular networks, the BS is located in the centre of the hexagonal cell. Six fixed relays are placed in each cell as new network elements enhancing the cellular infrastructure. Each relay is located on the line that connects the centre of the cell to one of the six cell vertices, and it is 2/3 away from the centre (BS) as shown in Figure 1.

3.2   System Model

WiMAX system level Simulator is shown in the Figure 2.The WiMAX system level simulator interfaces with the WiMAX link level simulator through LUTs as input to the simulator. Several propagation and traffic models are available, and the simulator computes the entire channel losses (slow and fast fading), thereby ensuring accuracy in the system level parameters computed. The outputs are the parameters that usually characterize packet transmissions: Throughput, BLER , Packet Delay etc.

The WiMAX traffic generation block contains real and non-real time service traffic models. Handover block, as the name suggests, includes the handover algorithm. The radio resource management block comprises a call admission control algorithm, to regulate the operation of the network; a link adaptation algorithm, to select the appropriate parameters in function of the current radio conditions and a scheduler that

Fig. 1. Cellular layout for Relay Nodes

decides how to allocate the appropriate resources, based on the service type, the amount of data, the current load in the cell, etc. The Power control block contains mechanisms to provide similar service quality to all communication links despite the variations in the channel conditions. The interference block determines the average interference power received by central base station, i.e.inter-cell interference.

Finally, the computation of WiMAX system level metrics block returns then network results such as Service Throughput(average spectral efficiency), Block Error Rate and Packet Delay. The mobility block models mobile movement in indoor, urban, and rural environments. Parameters associated with mobility include speed, probability to change speed at position update, probability to change direction, and the de-correlation length. The propagation block models path loss, slow fading and fast fading. Channel models for indoor environments, outdoor urban and rural environments are available.

Task Manger is responsible for overall coordination of the system. The scheduler mechanism will generate the arrival process of the users, according to a Poisson arrival process. The objective of Call Admission Control is to regulate the operation of a network in such a way that ensures the uninterrupted service provision to the already existing connections and at the same time accommodates in an optimum way the new connection request. The scheduler decides how to allocate the appropriate resources, based on the service type, the amount of data, the load on the common and shared channels, the current loading in the cell and the radio performance of each type of transport channel. Link adaptation can be considered as a component of Dynamic Channel Assignment.With the power control mechanism, similar service quality is provided to all communication links despite the variations in the channel conditions, which means larger proportion of the total available power is consumed for the bad channel conditions. Handover is common to all dynamic system level simulators, and required to maintain link quality at the cell boundaries. Simulation Map description of the cellular map, which includes the cell descriptions, base station locations, and the
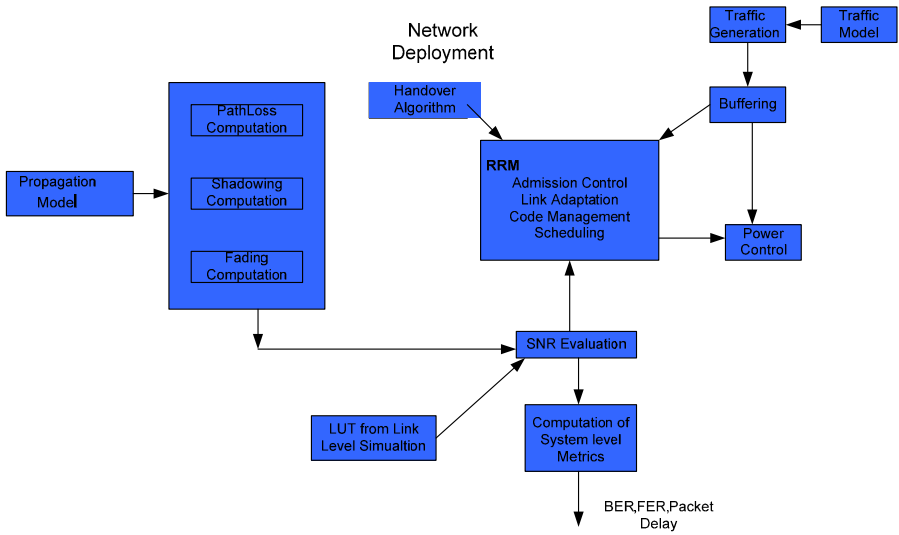
Fig. 2. WiMAX System Level Simulator

manner in which it will model mobile movement at the system boundaries. Simple ARQ is employed for non-real time services. Dynamic Channel Allocation algorithm provides extra performance, but is not a pivotal element in the simulator.

3.3 Relay Selection

In this WiMAX architecture, a UE has two choices to receive signals: either from the BS or from one of the six relays. A specific algorithm needs to be established to determine from which node (BS or one of the relays) a UE will receive its signal. An Effective SINR-based relay selection algorithm and pathloss-based relay selection algorithms are explained and compare through simulation . In our relay selection algorithms, we assume all six fixed relays are placed in strategic locations with good receiving signals from the BS.

3.4 Effective SINR-Based Relay Selection Algorithm

For OFDM with a sufficiently large cyclic prefix, there is no intra-cell interference even in case of a time-dispersive channel. However, this does not imply that OFDM performance will not suffer from a frequency-selective (timedispersive) channel. The reason is that, in case of OFDM and a frequency-selective channel, different coded bits will be subject to different instantaneous channel quality (different SIR). The Effective SINR(EESM) in WiMAX system is calculated using following formula:

$$\gamma_{eff} = -\beta \ln(\frac{1}{K}\sum_{k=1}^{k} e^{\frac{\gamma_k}{\beta}}) \tag{1}$$

γ_{eff} effective SNR where β is a parameter that must be optimized from link-level simulation results for every modulation and coding rate combination. Note that a subset of the K useful subcarriers could also be used to evaluate the effective SIR for reasons of computational efficiency. For more detail of EESM, see the WiMAX Forum. The Base Station and relay link is assumed to be good enough to support this mode of operation (due to strategic relay locations and high-gain antennas). Effective SINR based algorithm has two steps:

1) Out of the six relays (R1,...R6) in the cell in which the   UE resides, select two that are the closest to the UE   (R1, R2).
2) Compute the Effective SINR between the two closest   relays and the UE, and between the BS and the UE.

The node (relay or BS) with the maximum Effective SINR will be responsible for transmitting signals for the UE.

$$n_S = \arg\max \left\{ effSINR_{R1}, \; effSINR_{R2}, \; effSINR_{BS} \right\}$$
$$n_S : selected \;\; node \tag{2}$$

3.5   Path Loss-Based Relay Selection Algorithm

We take into consideration lognormal shadowing in addition to distance-based attenuation. The pathloss algorithm has two steps:

1) Out of the six relays in the cell in which the UE resides,   select two that are the closest to the user (R1, R2).
2) Compute the pathloss between the two closest relays and the UE, and between the BS and the UE.

Base station and Relay node use different Power level. The node (relay or BS) with the least pathloss will be responsible for transmitting signals for that UE.

$$n_s = \arg\min \left\{ PL_{R1}, PL_{R2}, PL_{BS} - \Gamma \right\}, \;\; n_s : selected \;\; node$$
$$\Gamma = 10 \log_{10} \left(\frac{P_{BS}}{P_{rel}} \right) \tag{3}$$

To increase the throughput and to extend the high data rate coverage, AMC is employed in this study which allows using different combinations of constellation sizes and code rates based on the channel conditions (or received Effective SINR values). The combinations of three modulation schemes (QPSK, 16- QAM, 64-QAM) and 2 code rates (1/2, , 3/4,) are considered. Table 1 depicts the relation between the received SINR value .The received SINR value determines which combination to use.

Table 1. Modulation and Coding with Received SNR

Modulation and Coding Rate		Received SNR(dB)	Bit/Symbol
QPSK	1/2	5	1536
	3/4	8	2304
16QAM	1/2	10.5	3072
	3/4	14	4608
64 QAM	1/2	18	4608
	3/4	20	6144

4   Simulation Results

We calculated pathloss as follow:

$$PL = A + 10\gamma\log(\frac{d}{d_0}) + s \qquad (4)$$

Where d_0 is 100m, $A = 20log(4\pi d_0/\lambda)$, λ is the wavelength, γ is pathloss exponent and s represents shadowing effect which follow log normal distribution with standard deviation 10 dB.

Beside simulation parameters mention in Table 2. We are using 1024 FFT size,5 OFDM symbol per frame,720 data subcarrier with PUSC scheme with 128 cyclic prefix length. The cluster size of the cellular network is taken to be equal to 4. Seven clusters are deployed, but the data is collected for the innermost cluster; i.e., the first tier . Both the BSs and UEs are assumed to use omni directional antennas with a gain of 10 dB. Power control is not considered in this simulation, because when AMC is used, power control does not contribute much towards the throughput increase. The BS transmit power is assumed to be 10 W. For the fixed relay transmit power, we consider a variety of values to compare the system throughput and performance: 0.1 W, 0.3 W or 1 W. Only the downlink scenario is considered. The UEs are placed randomly across the cluster with 40 UEs per cell.

In this simulation, we compare the with-relaying case with the without-relaying one. For the without-relaying case, all UEs will receive signals from the BS. In this case the interference comes from the other six BSs. The calculation of SINR is done by EESM. For the with-relaying case, as described above, six relays are placed in each cell. In this case, the received signal can be either from the BS or from a relay depending on which node the UE is communicating with. The interference structure in this case is different from that in the without-relaying case, because not only do we need to consider the interference generated by other BSs, but the interference from other relays . After calculating the SINR for both cases, Table 1 is used to find out the throughput (spectral efficiency). Figures 3 compare the average throughput for the two relay selection algorithms, pathloss and SINR, when R = 1000 m and without considering the interference from other cells (central cell approach).

Table 2.

Parameter Name	Value
WiMAX system	
Time transmission interval (T_{ti})	10 ms
Cell type	Omni or TriSector
Cell radius	100,200,…1000 m
Radio Resource Management	Best select CQI
Nominal bandwidth (W)	10 MHz
Base Station Power	10 W
Relay Node Power	1W,0.1W or 0.3W
Simulation type	Downlink
SINR method	EESM(Exp Effective SINR Mapping)
Channel Model	Urban
Carrier frequency	5 GHz
Channel model	ITU vehicular A
Mobile terminals velocity	30 km/h
Number of Users	40 per cell
Modulation and Coding	AMC
Traffic model	web3GPP No full Queue Option Cell Arrival Rate: 10 user/cell/Sec
Propagation model	Multipath channel model Path loss, shadowing and fast fading
Antenna gain	14 dBm
Duration call	90 s

Figure 4 compare the same thing, but this time we consider the interference from other cells. The throughput of the SINR-based algorithm is slightly better than that of the pathloss-based one in both cases. If SINR is difficult to implement, pathloss-based algorithm can be used with fairly good results.The throughput of the SINR-based algorithm is slightly better than that of the pathloss-based one, so from now we just use SNR-based algorithm. Figure 5 shows the average spectral efficiency with respect to the relay positions for 1000 m and 500 m cells. As discussed before, the relays are placed on the segment between the centre and one corner of that cell.

Here the relay position is indicated by a parameter **m** showing how far away the relay is from the BS. Refer to Figure 1.

$$m = \frac{a}{R} \tag{5}$$

where **a** is the distance from the BS to the relay, **R** is the distance from the BS to one corner of the cell. In the simulation, the following m values are examined: 0, 0.1, 0.2,

… , In addition, the results corresponding to the *m* values that are 2/3, 3/4 and 7/8 are also given out in Figure 4. The results for the *m* = 0 case corresponds to the no relay case.The simulation results show that the best range for the relay position is 2/3 to 3/4 away from the BS, when the transmit power ratio of the BS and the relay is 10:1. It agrees with our relay position design.Fixed relays can also help extend the system coverage. Figures 5 shows the average spectral efficiency, to show the coverage extension brought in by fixed relays in large, medium and small cells.
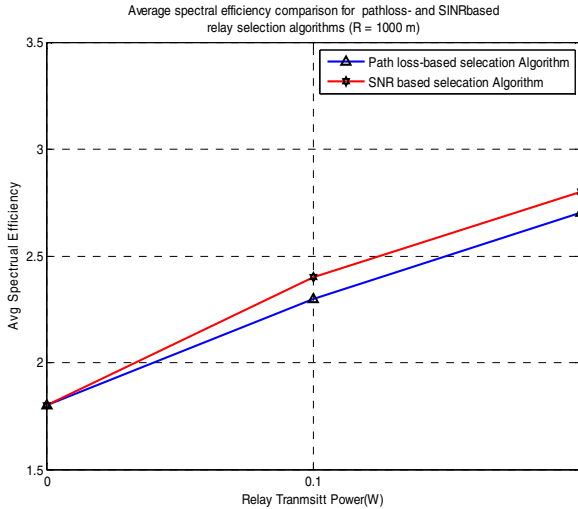
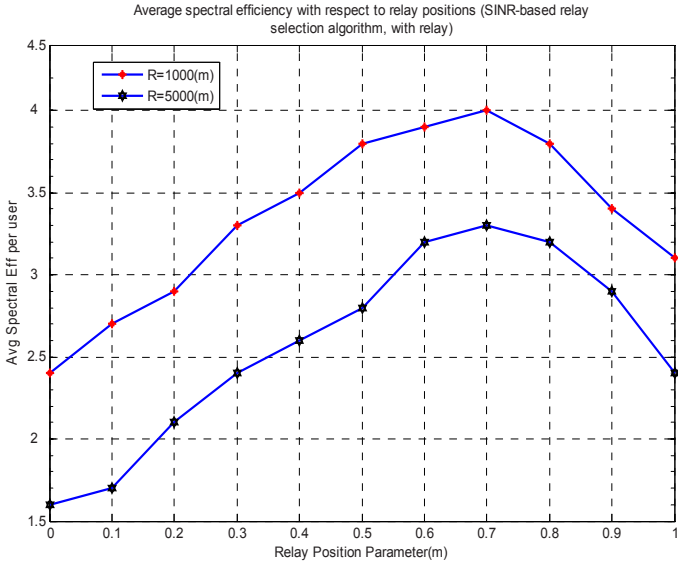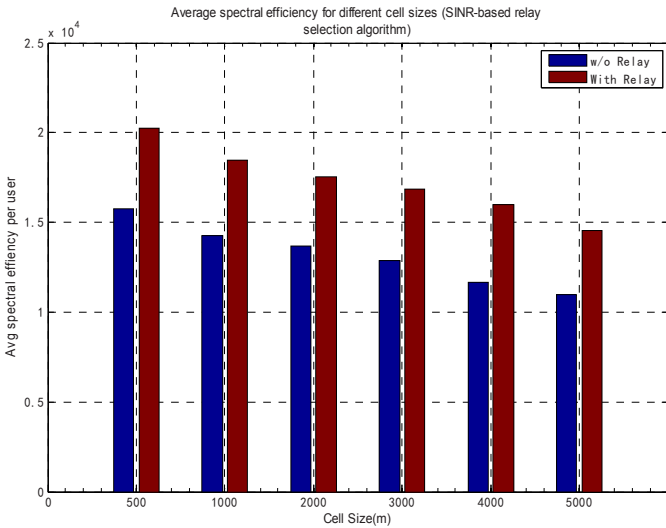**Fig. 3.** PathLoss Vs SINR based algorithm (without interference)
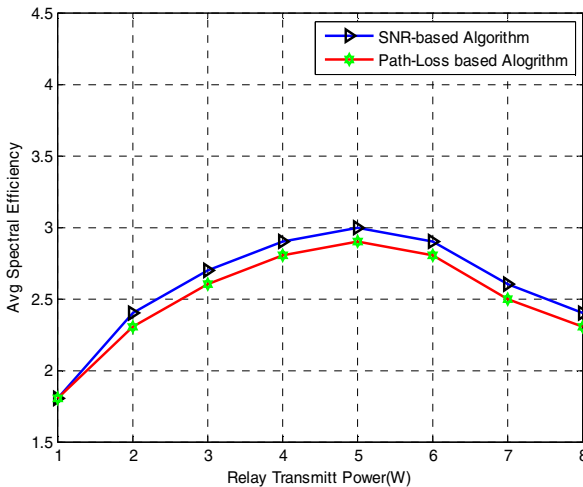
Fig. 4. PathLoss Vs SINR based algorithm (with interference)

Average spectral efficiency with respect to relay positions (SINR-based relay selection algorithm, with relay)

Fig. 5. Relay Position with respect to BS

Average spectral efficiency for different cell sizes (SINR-based relay selection algorithm)

Fig. 6. Average Spectral efficiency for different cell size

For example, in Figure 6, an average spectral efficiency of 3.7 bits/sec/Hz can only be achieved in a small cell (500 m) without relays, while the same amount of average spectral efficiency can be achieved in a medium cell (1000 m) with the help of relays. In other words, the system coverage with relays is four times as much as the coverage without relays, because the coverage area is proportional to the square of the radius.

Figure 7 shows the percentage of users communicating with relays when $R = 2000$ m and 500 m. A conclusion can be drawn from Figures 6 is that the higher the relay transmit power is, the higher percentage of users will communicate with relays. Figure 8 represents the overall system throughput with relay and without relay case.
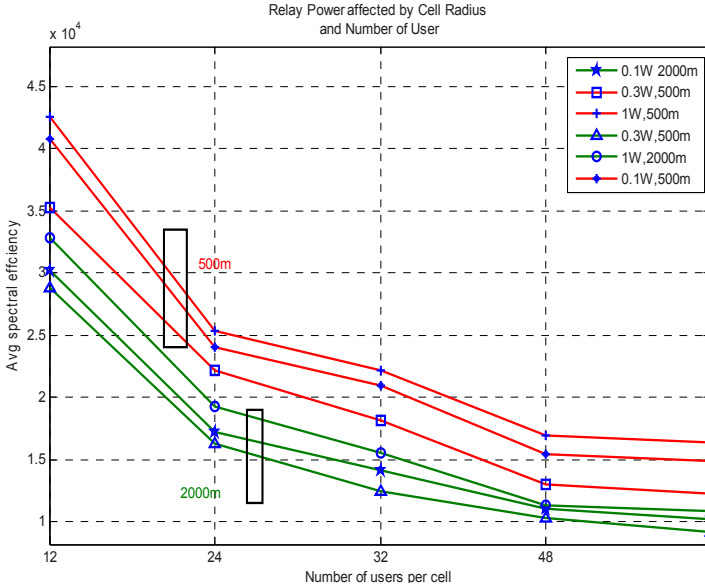

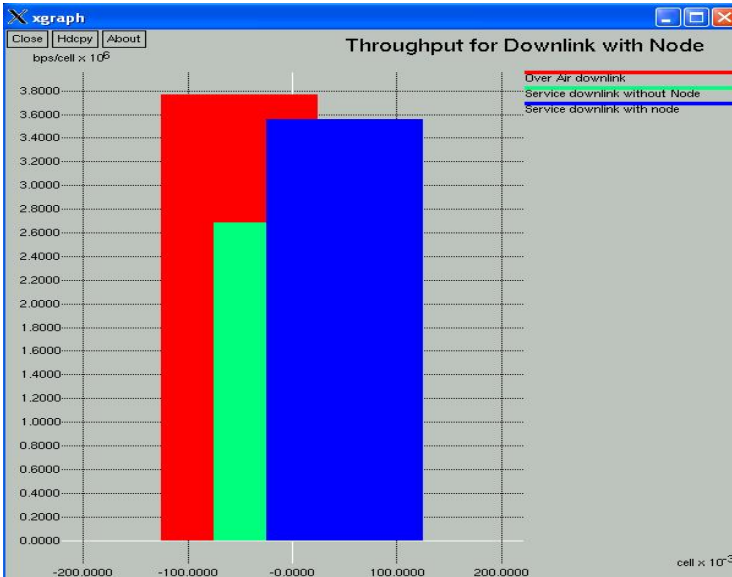**Fig. 7.** Relay Power affected by Cell Radius

Fig. 8. Overall System Throughput

5 Conclusion

Deployment concepts using fixed relay stations have been shown to be of high benefit to substantially reduce the cost of interfacing BS to the fixed network (owing to a substantial reduction of BS needed). Relays have been proven to substantially extend the radio coverage of an BS, especially in highly obstructed service areas. From the simulation results, we can conclude that fixed relaying is a simple yet effective approach to improve system throughput and high data rate coverage. The SINR-based algorithm produces the greatest throughput improvement, however it involves more signalling. Furthermore, as far as the relay position is concerned, we can tell from the simulation results that the best performance can be attained with the placement of relays at 2/3 to ¾ away from the BS, when the transmit power ratio of the BS and the relay is 10:1. Nearer or farther from the BS will weaken the SINR values.

Acknowledgements

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