Performance Analysis of the IEEE standard 802.16a

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Abstract — **The IEEE *802.16*a standard ($WiMAX$) which has emerged as a broadband wireless access technology, promise to deliver high data rates over large areas to a large number of users in the near future. This exciting addition to current broadband options such as DSL, cable, and WiFi promises to rapidly provide broadband access to locations in the worlds rural and developing areas where broadband is currently unavailable, as well as competing for urban market share. This paper first provides an intoduction to IEEE *802.16*a MAC Layer. Then, based on extensive simulations, this paper presents the realistic attainable throughput and performance of expected $WiMAX$ compatible systems based on the IEEE *802.16*a Standard in various Low and High Density Networks. In this paper, throughput of Hybrid Wireless Networks is theoretically calculated.**

Keywords: $WiMAX$, IEEE *802.16*a , MAC, Throughput, Mesh Mode, GloMoSim

I. INTRODUCTION

A. MAC Layer

The IEEE *802.16*a MAC [1] layer performs the standard Medium Access Control (MAC) layer function of providing a medium-independent interface to the $WiMAX$ Physical (PHY) layer. Because the $WiMAX$ PHY is a wireless PHY layer, the main focus of the MAC layer is to manage the resources of the airlink in an efficient manner. The $WiMAX$ MAC protocol is designed to support Point to Multipoint (PMP) and Mesh network models.

$WiMAX$ MAC is designed to meet the requirements of very-high-data-rate applications with a variety of Quality of Service (QoS) requirements. It performs link adaptation and Automatic Repeat Request (ARQ) functions to maintain target Bit Error Rates (BER) while maximizing the data throughput. The MAC layer schedules the usage of the airlink resources . The signaling and bandwidth allocation algorithms have been designed to accommodate hundreds of terminals per channel. The standard allows each terminal to be shared by multiple end users. The bandwidth request and grant mechanism has been designed to be scalable, efficient, and self-correcting. It takes advantage of a wide variety of request mechanisms, balancing the stability of contentionless access with the efficiency of contention-oriented access. Its MAC layer also handles network entry for SSsthat enter and leave the network.

Finally, the MAC layer provides a convergence sub layer that supports Asynchronous Transfer Mode (ATM) cell- and packet-based network layers.

B. General Network Configuration

The most common $WiMAX$ configuration consists of a base station mounted on a building or tower that communicates on a point to multi-point basis with subscriber stations located in businesses and homes. $WiMAX$ has a range of up to 30 miles with a typical cell radius of 46 miles. Within the typical cell radius, non-line-of-sight performance and throughputs are optimal. In addition, $WiMAX$ provides an ideal wireless backhaul technology to connect IEEE *802.11* wireless LANs and commercial IEEE *802.11* hotspots with the Internet.

C. GLObal MObile Information System SIMulator - GloMoSim

The simulations have been performed using the GloMoSim Network Simulator developed at UCLA [2]. This simulator models the OSI seven layer network architecture and includes models of IP routing and UDP. We simulated the $WiMAX$ MAC layer under many situations. The study has been categorised into many scenarios, with each scenario being further subdivided into a number of cases, wherein some aspects of the MAC have been studied. We have used the PMP mode implementation of IEEE *802.16*a in GloMoSim by [4].

II. SIMULATION SCENARIOS

A. Low and High Density Wireless Networks

In this scenario, we tested the performance of the protocol if it were to be deployed on a campus wide scale. Here we modelled various parts of the campus, i.e., hostels,residential areas and various departments as subscriber stations (SS) and a centrally located base station(BS). A particular SS was modelled as the server, and consequentially, all the other nodes directed requests towards that subsriber station.

We carried out the simulation under HTTP as well as FTP traffic. It was assumed that the traffic from the areas like hostels and the departments is much higher than that from residential areas. Thus ,in our traffic model we assigned different weights to the traffic from such areas to the server. We also took into account some traffic between the various subsribers themselves.

B. Hybrid Wireless Networks

In this scenario, we looked into the performance of a hybrid wireless network. We studied the effects of increasing the number of base snd subscriber tations on the bandwidth utilization in this network and also proved

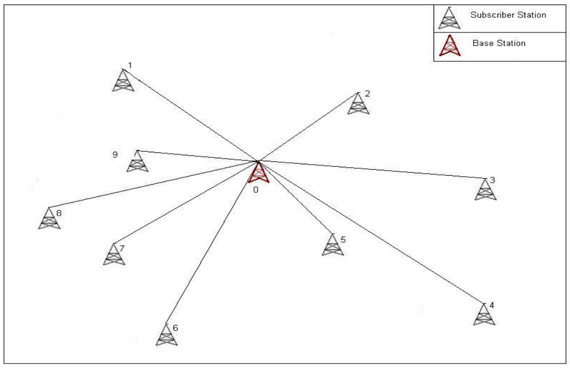

Figure 1: One Base Station Having Several Subscriber Stations

some results under which bandwidth utilization is maximized.

III. Low and High Density Wireless Networks

$WiMAX$ can be deployed in a wide variety of configurations and settings. In a typical campus-wide network, $WiMAX$ can be used both in a low density as well as a high density wireless network configuration. In this chapter, we study the performance of IEEE *802.16*a in low and high density network configurations. In both configurations, the number of subscriber stations (SS) are assumed to be the same. This is a valid assumption since both these networks serve the same campus. The number as well as arrangement of base stations (BS) in the two settings is varied and the performance of the resulatant network has been studied. We have assumed a model of a low density network where a single BS controls a fixed number (say x) of SS. On the other hand, in a high density network, the number of BS are increased. Also, the BS are arranged in a typical tree type hierarchy. Thus there is one ”main” base station, which controls multiple ”sub”-base stations, which in turn control the subsriber stations. By varying the number of BS in a high density network, we arrive at an optimum configuration for such a deployment of $WiMAX$.

A. Low Density Network

In Figure 1, node 0 is the Base station (BS) and nodes 1-9 are the subscribers (SS). This scenario has been modeled on the IIT-Delhi campus. This is a simple version of the campus network. with various parts of the campus serving as the SS.

B. High Density Network

Here, node 0 is the main Base station, which has nodes 10, 11, 12 as its subscribers, as shown in Figure 2. There is a two level hierarchy of BS-SS.

Both the cases were studied under 3 kinds of traffic HTTP, CBR, FTP. The traffic model took under consideration aspects like the relative traffic between various parts of the campus, as well as the relative network load and demand of various regions. For example, network load and demand from the hostels is significantly heavier than that from the residential areas.

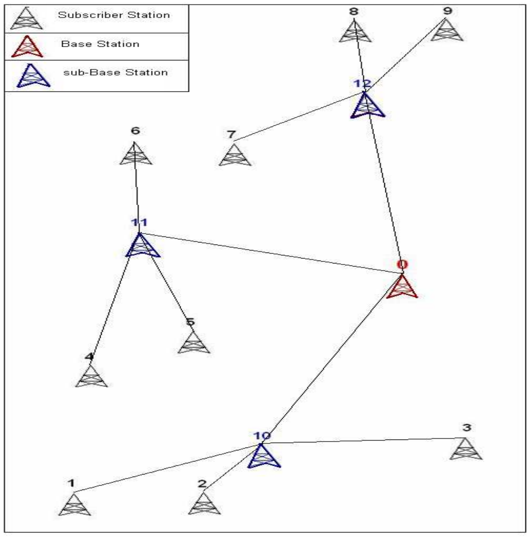

Figure 2: Base Station having sub-Base Stations

C. Results

Consider a base station(node 0) serving x subscribers. Let the total bandwidth used on the downlink by BS be N. Now let us assume that n more nodes are added in between node 0 and the SS. these n nodes act as SS for node 0 and as BS for the x subscribers. Thus eventualy, there are $(n+1)$ BS and x SS. Assume that the SS are evenly distributed between all the BS, i.e, all BS control equal number os SS, viz. x/n .

When there is only 1 BS, average bandwidth used by each $SS = N/x$.

Assuming that the traffic between each pair of subscribers is uniform, the average bandwidth dedicated to traffic from a node i(say) to a node j is $\frac{N}{x(x-1)}$.

When n more nodes are added, the bandwidth allocation changes. Consider a SS, say node i, such that $1 \leq i \leq x$. Traffic from i to another SS (say node $j, 1 \leq j \leq x, j \neq i$) will route through node 0 if i,j have different BS. Since there are $\frac{x}{n}$ SS which have the same BS as node i, there are $(x - \frac{x}{n})$ choices for the node j. Hence, the total bandwidth used at node 0, due to traffic from node i to all other SS is $(x - \frac{x}{n})\frac{N}{x(x-1)}$.

Again, there are x choices for the node i.Thus the total bandwidth$f(n)$ used on the downlink for node 0 becomes

$$f(n) = x\frac{N(x - x/n)}{x(x-1)} = \frac{Nx(1-\frac{1}{n})}{x-1}$$

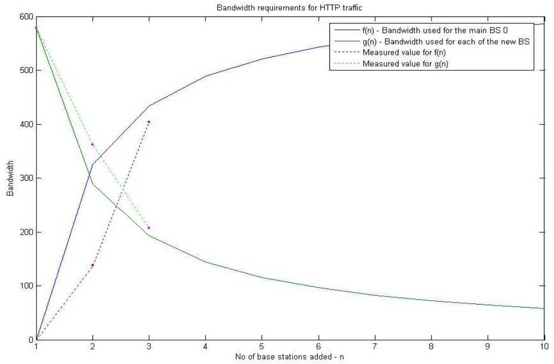

Figure 3: f(n) and g(n) versus n and Bandwidth is in kbps

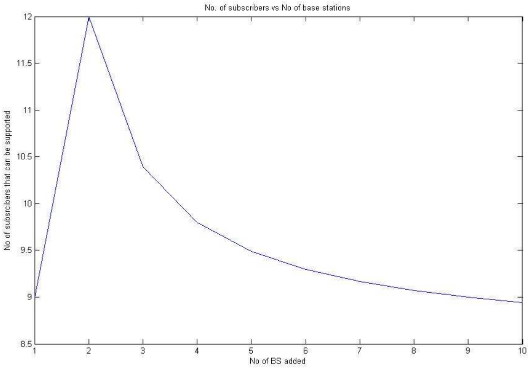

Figure 4: Number of SS is maximum for 2 intermediate BS

Theorem 1 *If initialy there are x SS being controlled by a single BS, and n more nodes are added which serve as BS to the x SS but as SS to the initial BS, then the bandwidth utilisation($f(n)$) at the main BS changes from N to*

$$f(n) = \frac{Nx(1-\frac{1}{n})}{x-1}.$$

Theorem 2 *Consider one of the newly added n nodes in the scenario in Theorem 1. The bandwidth used by this node(say node k) is given by*

$$g(n) = \frac{N}{n}.$$

Proof : Node k acts as a BS for x/n SS. Each of these x/n SS communicate with all other $(x-1)$ SS.Thus, the bandwidth used on the downlink by this node k is $\frac{x}{n}\frac{N}{x(x-1)}(x-1) = \frac{N}{n}$. This also gives us a corollary:

Corollary 1 *For optimum utilisation of the network, $n = 2$. This is evident as if we solve $\lim_{x\to\infty} f(n) = g(n)$ (for large number of SS - typically about 50) we get $n = 2$.*

Figure 3 shows the plot of $f(n)$ and $g(n)$ versus n in HTTP Traffic.

Let n_0 be such that $f(n_0) = g(n_0)$. Then $n_0 = 1 + (x-1)/x$. is the optimum value of the number of BSs for bandwidth of all the BSs to be kept to a minimum. n_0 tends to 2 if the number of subscribers is very large.This observation is also justified from Figure 4.

Let us now keep the bandwidth used on the downlink constant and add new SS to the network. This is possible as the reduction in BS's bandwidth usage permits us to add more SSs. Let us assume that y further SSs can be added after adding n more BSs so as to maintain the bandwidth usage at N. Again, the bandwidth used per subscriber per node(considering any two pairs of nodes i, j) is $\frac{N}{x(x-1)}$. If y more subscribers are added, The total bandwidth used at node 0 due to traffic between two SS (i, j say) not having the same BS becomes $\frac{N}{x(x-1)}$ For each SS i, there are $(x+y) - \frac{(x+y)}{n}$ choices for SS j. Also there are $(x+y)$ choices for SS i itself. As a result, the total badwidth used at node 0 becomes $(\frac{N}{x(x-1)})n(n-1)(\frac{(x+y)}{n})^2$ Now to find the maximum number of subscribers possible, we equate this expression to N and solve to get,

$$z = (x+y) = \sqrt{\frac{nx(x-1)}{(n-1)}}$$

Theorem 3 *If there are x SS being controlled by a single BS initially, and n more nodes are added which serve as BS to the x SS , then the bandwidth utilisation at the main BS reduces. As a result the network is capable of supporting more SS. The maximum number of SS z that can be supported is given by z.*

Corollary 2 *To maximize the number of SS that can be added, 2 nodes should be added between main BS and the SS. This is evident as in the previous theorem, z maximizes for $n = 2$. This also agrees with our earlier result that to maximize the bandwidth used $n = 2$.*

IV. HYBRID WIRELESS NETWORKS

A hybrid wireless network is formed by placing a sparse network of base stations in an ad hoc network. These base stations are assumed to be connected by a high-bandwidth wired network and act as relays for wireless nodes(subscriber station). Furthermore, we assume the link bandwidth in the wired network is large enough so that there are no bandwidth constraints in the wired network. A node connects to the nearest base station in order to communicate with other nodes. Using such a network, we can increase the communicating distance between any two nodes since any two nodes having distinct base stations can still communicate. One of such a hybrid wireless network is shown in Figure 5.

Let X_i denotes any node and $Base(X_i)$ denotes the nearest base station to X_i. Let any node X_s wants to

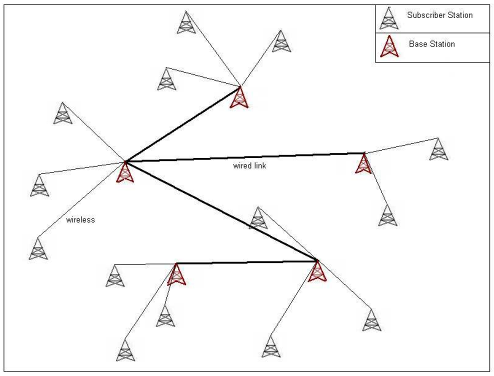

Figure 5: A hybrid Wireless Network

transmit some data to a node X_t, if X_s and X_t are not associated to the same base station then the data is first transmitted from source X_s to $Base(X_s)$ over the PHY: the base station then transmits data through the wired infrastructure to $Base(X_t)$, which finally transmits the data to destination X_t. Let our hybrid network contains N base stations and $f(j)$ be the number of subscriber stations associated with base station j. Here, association of a node X_i with base station j means $Base(X_i) = j$ for all $j = [1, 2, ...N]$. Therefore, if N and M are the total number of base stations and subscriber stations respectively in our network, then $M = \sum_{j=1}^{N} f(j)$.

Definition 1 *A cell is the region covered by a base station j and its subscriber stations.*

We assume that each node can transmit B bits/sec over the wireless channel. We divide the wireless channel so that mesh mode transmissions and base station transmission go through different sub-channels. We further divide the base station traffic into uplink and downlink traffic, according to the direction of transmissions relative to the base station. Since mesh mode and base station uplink and downlink traffic use different sub- channels, there is no interference between the three types of traffic. The bandwidth assigned to each of three subchannels is B_1, B_2, B_3 respectively. Also $\sum_{i=1}^{3} B_i = B$

Theorem 4 *For a hybrid network of N base stations and total M subscriber stations, if subscriber stations are probablistically(p) deciding between the mesh mode and PMP mode then per cell throughput capacity of the network is given by*

$$T_{total} = \Theta(\sqrt{\frac{pm/N}{log(pm/N)}}B_1 + B_2 + B_3)$$

Proof : Assume that no node of one cell is in the communicating radius of any node of other cell. Let the destination for a source node is randomly chosen, then the probability that a node X_i does intra-cell communication is

$$p(X_i)_{intra} = \frac{f(Base(X_i))}{M}$$

and the probability that a node X_i commits inter-cell communication is $1 - p(X_i)_{intra}$. Let I_i be a random variable that represents whether X_i commits intra-cell or inter-cell communication.

$$I_i = \begin{cases} 1 & X_i \text{ commits intra-cell communication} \\ 0 & \text{otherwise} \end{cases}$$

For any base station B, we can number its subscribers from 1,2,. . .,f(B) and one can easily see that $(I_i)_1^{f(Base)}$ is an identical independently distributed(i.i.d) sequence of random variables with expectation $E[I_i] = p(X_i)_{intra}$. Now let us find out the per cell capcity. Let $M_{intra} = \sum_{i=1}^{f(Base)} I_i$ be a random variable representing the number of nodes in a cell which commits intra-cell communication. If the node X_i does intra-cell communication, then it can either transmit data via base station or use mesh mode. Let p be the probability that a node chooses mesh mode to transmit data. Let C_i be a random variable that represents whether X_i uses BS or mesh mode for communication if the destination node is in the same cell as of the source.

$$C_i = \begin{cases} 1 & X_i \text{ chooses mesh mode} \\ 0 & \text{otherwise} \end{cases}$$

We can see that $(C_i)_1^{f(Base)}$ is an i.i.d sequence of random variables with $E[C_i] = \frac{f(Base)}{M}p$. Now let us find out the per cell capacity. Let $M_{mesh} = \sum_{i=1}^{f(Base)} C_i$ be a random variable representing the number of nodes which transmits data using mesh mode in a cell. Clearly,

$$M_{mesh} \leq M_{intra}$$

We first calculate the per cell throughput contributed by the mesh mode transmissions. For simplicity, assume that number of nodes in each cell are m such that $Nm = M$ i.e. $f(Base) = m$. Therefore $E[C_i] = \frac{p}{N}$. By Strong Law of Large Numbers,

$$\frac{M_{mesh}}{m} = \frac{\sum_{i=1}^{m} C_i}{m} \to \frac{p}{N} \quad as \quad m \to \infty. \tag{1}$$

We have $lim_{m\to\infty}\frac{mp}{N} \to \infty$, and thus $lim_{m\to\infty}M_{mesh} \to \infty$. According to [8], for a wireless network of M_{mesh} nodes and a common transmission rate of B_1, if $M_{mesh} \to \infty$, per node capacity is $\Theta(\frac{B_1}{\sqrt{M_{mesh}logM_{mesh}}})$ and for M_{mesh} nodes it would be $T(M_{mesh}) = \Theta(\sqrt{\frac{M_{mesh}}{logM_{mesh}}}B_1)$. Denote,

$$k_1 = lim_{m\to\infty}inf\frac{T(M_{mesh})}{\sqrt{\frac{M_{mesh}}{logM_{mesh}}}B_1}$$

$$k_2 = lim_{m \to \infty} sup \frac{T(M_{mesh})}{\sqrt{\frac{M_{mesh}}{logM_{mesh}}}B_1}$$

.

By (1), we also have $lim_{m \to \infty} \frac{\sqrt{\frac{M_{mesh}}{logM_{mesh}}}}{\sqrt{\frac{pm/N}{log(pm/N)}}} = 1$. Therefore,

$$lim_{m \to \infty} inf \frac{T(M_{mesh})}{\sqrt{\frac{pm/N}{log(pm/N)}}B_1}$$

$$= lim_{m \to \infty} inf \frac{T(M_{mesh})}{\sqrt{\frac{M_{mesh}}{logM_{mesh}}}B_1} \frac{\sqrt{\frac{M_{mesh}}{logM_{mesh}}}}{\sqrt{\frac{pm/N}{log(pm/N)}}} i = k_1.$$

Similarly,

$$lim_{m \to \infty} sup \frac{T(M_{mesh})}{\sqrt{\frac{pm/N}{log(pm/N)}}B_1} = k_2$$

So the term $lim_{m \to \infty} T(M_{mesh}) / \sqrt{\frac{pm/N}{log(pm/N)}}B_1$ is bounded by constants k_1 and k_2. Therefore, the per cell throughput capacity contributed by mesh mode communication is,

$$T_{mesh} = \Theta(\sqrt{\frac{pm/N}{log(pm/N)}}B_1) \tag{2}$$

Now we calculate the per cell capacity contributed by base station communications.First consider the uplink throughput. In order to utilize the base station capacity, at least one node should use base station for communication purpose. Since all the traffic in this mode has to go through the Base Station and the base station can only receive data at the rate of B_2 bits/sec at any instant. Let P denotes the probability that all nodes of a cell use mesh mode to communicate. Then,

$$T_{uplink} = \Theta(B_2)(1 - P)$$
$$T_{uplink} = \Theta(B_2)(1 - (p/N)^m)$$

If m goes to infinity and $p < 1$,

$$T_{uplink} = lim_{m \to \infty} \Theta(B_2)(1 - (p/N)^m)$$
$$T_{uplink} = \Theta(B_2) \tag{3}$$

Similarly,

$$T_{downlink} = \Theta(B_3) \tag{4}$$

As $m \to \infty$, probability that at least one node chooses base station communication in a cell approaches 1, that means the bandwidth of base stations is fully utilized. If any node commits intra-cell communication then to maximize the throughput it should use mesh mode i.e. $p \to 1$.

Corollary 3 *Per cell throughput capacity is maximized when* $M_{mesh} = M_{intra}$.

V. CONCLUSION

This article overviews key aspects of the IEEE 802.16 standard, and demonstrates the expected performance for 802.16-based fixed wireless broadband systems.

We also saw that the best configuration for achieving high data rates is one where the main BS has 2 SS which further act as BS for a number of nodes. This was further validated in the simulation scenarios.

In a hybrid wireless network, if a subscriber station has a choice between PMP and mesh mode, then the total throughput is maximized if it selects mesh mode for intra-cell communication.

VI. FUTURE WORK

Mobility - If nodes in a network become mobile, then it will be interesting to study their effect on network throuput. Mobility of nodes is supported in IEEE *802.16*e standard.

Mesh Mode - Statistically, we have done the performnce analysis of the $WiMAX$ protocol only in PMP (Point to MultiPoint) Mode i.e. Subscriber Stations in a network can only communicate with each other through a Base Station, but in mesh mode, they can transfer data between them without the interference of a Base Station.

GloMoSim - Future work can be carried out to improve the accuracy of the model and implement some other features that are defined in IEEE *802.16*a . The performance analysis of QoS features can subsequently be carried out.

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