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EFFICIENT DECISION HANDOFF MECHANISM FOR HETEROGENEOUS NETWORKS

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ABSTRACT

Heterogeneous networks that contain overlapping coverage of several wireless access technologies enabling better spectrum efficiency and utilization are becoming common. In this work we focus specifically on WiMAX technology running at the outer cell and Wi-Fi technology applied in the inner cells. We define a system-wise entity that is activated when a user is in an area with over-lapping access technologies and needs to decide what is the best technology to be used, where the entity performs technology selection in order to optimize the overall system performance metric in terms of throughput and capacity limitation. Our simulation results validate the efficiency of our method and show that it is also applicable to other combinations of access technologies.

KEYWORDS

Wireless Networks, Heterogeneous Networks, System Decision Function, Wi-FI, WiMAX

1. INTRODUCTION

Heterogeneous networks that contain overlapping coverage of two wireless access technologies are becoming more and more frequent, and enable better spectrum efficiency. The specific topology of interest is when one technology (outer cell) covers a certain geographic area and within its covered area there are several cells of the second technology (inner cells); see Figure 1 for a topology illustration [2]. In this work we focus specifically on WiMAX as the outer cell and Wi-Fi as the inner cell technologies, although our results are also applicable to other combinations of access technologies.

WiMAX (802.16e) [12] is an emerging standard of wireless networking designed to provide the last mile of high speed Internet access to the end user. WiMAX is designed to enable high-speed mobile and fixed Internet access to the end user; as a fourth generation (4G) technology, WiMAX is an all-IP solution striving to provide services for data, video, and voice. WiMAX is a WMAN (Wireless Metropolitan Area Network) and, as such, can cover a wide geographic area, especially when taking into account its OFDMA (Orthogonal Frequency Division Multiple Access)-based physical layer, which enables it to operate in an NLOS (non-line-of-sight), resulting in the ability to cover wide cells in urban and sub-urban areas [17].

When deployed in a large area, with a large number of subscribers, the WiMAX technology, even if supporting advanced spectrum usage techniques such as adaptive modulation, and advanced antenna usage such as MIMO (Multiple In Multiple Out), STC (Space Time Coding), and BF (beamforming), can still operate in a capacity-limited scenario. This means that the system is overpopulated and there are not enough resources to share. In such cases, combing with other radio technology or radio access networks (MAN) can be beneficial to successfully meet the system demands.

Wi-Fi [10] generally refers to any type of 802.11 networks. The standard defines the protocol and compatible interconnection of data communication equipment in a local area network (LAN) using the carrier sense multiple access protocol with a collision avoidance (CSMA/CA) medium-sharing mechanism. An access point (AP) sends out a wireless signal that wireless devices can access within a cell radius of roughly 100 meters in open space. Within the coverage of an AP, connected devices can receive high speed data connections.

Handoff occurs when a mobile node (MN) moves from one wireless base station to another. It can be classified into horizontal and vertical cases. Horizontal handoff occurs when the mobile node moves between similar wireless networks, while vertical handoff occurs when movement is between heterogeneous wireless networks. Vertical handoff (VHO) is considered to be an important capability of the next wireless communication era.

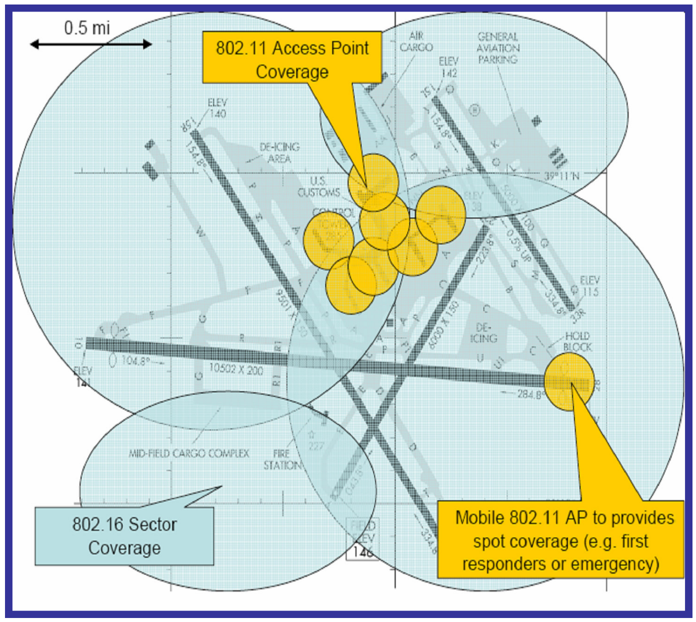


Figure 1. Example of Wi-Fi and WiMAX mesh network in Baltimore-Washington International Airport.

2. PREVIOUS WORK

There are three main approaches for vertical handover decision functions. The first approach is based on strategy using the received signal strength (RSS). The second approach is based on user mobility (direction and current location), while the third approach combines several metrics in a cost function estimated for the available access networks, which is then used in the user handoff decision. All of these approaches may also consider other network parameters.

Chen et al. [3] proposed a smart decision function based on the properties of available network interfaces (link capacity, power consumption, and link cost), system information (remaining battery), and user preferences. Moreover, the authors [3] presented detailed testbed experiments, but their work lacks sufficient information on how to describe the user preference, and validation examples. Singhrova and Prakash [18] reviewed the decision function based on three input parameters, namely received signal strength (RSS), cost, and bandwidth. Neither of the above papers took into account the velocity and current position of the user.

Wang et al. [19] presented a decision function considering bandwidth, latency, power consumption, charge model of the user with load, and traffic of the network. The velocity and current location were taken into account in order to switch to a technology that can serve a high speed user or inform a network for a future handoff. One of the disadvantages of the cost function is that it assumes that the connection is not free of charge in Wi-Fi technology. Hasswa et al. [9] discussed the different factors and metric qualities for a decision function and presented a generic Vertical Handoff Decision Function (VHDF). The function is based on generic network factors such as monetary cost, quality of service, power requirements, and mobility (velocity and current position). The authors considered the factors without proper simulation of analytical results. Garg and Choong [7] considered a decision function based on estimation of effective data rate, network latency, congestion, and signal strength. Moreover, one of the focuses of their paper [7] was how to estimate the location of the user in order to get the nearby APs. However, no explanation was given of how to estimate the parameters, when and how the decision function takes action, and included no simulation results. Choi et al. [4] proposed a decision rule based on theoretically computed throughput; however, they proposed a threshold considering the velocity and the current location (only if the speed does not exceed a certain threshold can the VHO occur). Kang et al. [15] showed an autonomic decision model for 4G networks using various characteristics, such as capacity link, usage charge, power consumption, battery status, and user preference. However, they considered VHO between Wi-Fi and Cellular technologies without presenting any simulation results. In [6] the authors have shown a decision function that combines triggers, and maintains and maximizes the user throughput (link quality, current cell load). The decision function is triggered when the signal to interference noise ratio (SINR) level of the current call drops under a certain threshold or by a performance trigger that combines the data rate and the network load in order to maximize MAC layer performance. Since the SINR level is checked periodically there is a tradeoff in battery consumption. Goyal and Saxena [8] presented a decision function for the 4G wireless networks that calculates a score function based on RSS, velocity, system information, and user preferences. This calculation is made for each candidate network. The network having the largest score function value is selected as the “best” network for the handoff.

All the vertical handover techniques mentioned above basically employ selection of a technology/network for handover. Such selection is usually based on current available information and is optimized for the current status of the user.

In order to save battery power in the two technologies scenario, one of the questions is when to activate the Wi-Fi hardware (of the mobile node). Recently, Izumukawa et al. [14] showed that movement from an outdoor cellular area into an indoor area can be estimated using the cellular signal strength. When a mobile node gets into an indoor area there is a huge difference in the cellular signal and the WLAN interface can then be activated. Another question is how a mobile node will choose the best AP under a Wi-Fi network. One of the possibilities of the mobile node is to scan the channels within its range and find a list of APs from all channels. Then, out of this list of APs, the host chooses the AP with the strongest receive power. Another possibility is to use solutions from 802.21 [13].

3. DECISION FUNCTION

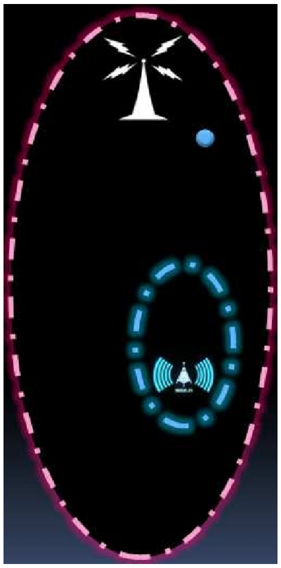
The main idea of any decision function is to keep an “always on” user service experience and to vertically hand over the user between technologies while taking into account the system status.

We propose a decision function (DF) in which the system considers all the available network and user parameters (e.g., host velocity, battery status, Wi-Fi AP’s current load, and WiMAX BS QoS guaranties), and performs technology selection such that an overall system performance metric is optimized (i.e., throughput and capacity limitation).

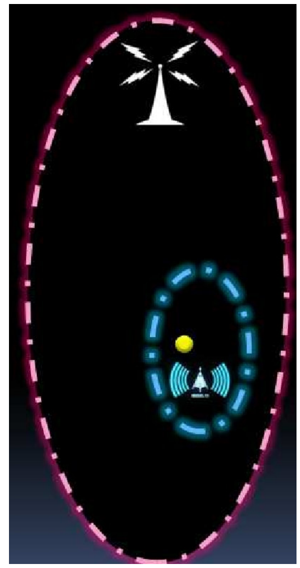
As said above, the DF takes into account several system parameters, which can be divided into Host, AP, and BS parameters. The host related parameters are: Velocity vector (Vu), expected length of the session (T_{sess}), and battery status (B_u). The Wi-Fi AP related parameters are availability and RSS value (with regard to the relevant host), denoted by RSS_{wifi}. Similarly, the WiMAX BS related parameters are: availability and RSS value, denoted by RSS_{wimax}.

The AP availability is defined by the number of connected subscribers, while the BS availability is defined as a function of its load (number of connected subscribers), and since the WiMAX BS supports QoS, with differentiation of connection types [12], i.e., Best Effort (BF), Real-Time Polling Service (rtPS), Non-Real-Time Polling Service (nrtPS), and Unsolicited Grant Service (UGS), it also contains specific admission control functionality [5, 20].

The session time is basically unknown; however, we may approximate the session time using a statistical traffic model, which depends on the session type (voice, video, or data) [11]. The battery usage function calculates power use during the connection to a specific technology. Location period in a Wi-Fi zone needs to consider the session time, velocity, and current position of the user. Using the position and velocity of the user, the system can approximate the time the user will spend in the Wi-Fi zone (T_{rem}). In Figure 2 we can see a scenario where automatic connection to Wi-Fi without taking into consideration the influence of the velocity and current position can lead to denied service.



(a) Getting service from WiMAX.



(b) The decision function decided to switch to Wi-Fi.

(c) The WiMAX system denied the user.

Figure 2. Velocity and current position.

In order to take into consideration the QoS and call admission of WiMAX we used the algorithms suggested by [5, 20] that can support diverse classes of traffic with different QoS requirements in terms of bandwidth and maximum delay (note that we assume only one active connection per subscriber). To support all types of service flows (UGS, rtPS, and BE), the proposed uplink packet scheduling (UPS) [5, 20] uses a combination of strict priority service discipline, earliest deadline first (EDF), and weight fair queue (WFQ). In order to simulate an appropriate admission control process in the simulation, we implemented an admission control model [5, 20]. This model, residing in the base station, will take into account the call parameters, host parameters, and the base station load, before establishing a new connection with the host.

The system-wise entity (Figure 3) is called when a user is in an area that consists of overlapping access technologies and needs to decide which is best. In order to do that, the system calculates the remaining time in the Wi-Fi zone (T_{rem}) and compares it to the session time (T_{sess}). If the session time is less than the estimated time, the best network is Wi-Fi. If not, the system checks if the user has enough battery power to connect the BS. Then, depending on the connection type the system needs to guarantee the QoS of the connection; if we cannot guarantee the QoS we have to choose Wi-Fi. Finally, the system compares the RSS of both technologies and chooses the better one as the technology to connect to.

4. ENVIRONMENT

We used an OMNET++ environment [1] with Pentium 4, 2G RAM, 1.8 Ghz processor, and Windows XP as OS. Network behavior in a specific scenario is based on predefined parameters:

- The width of the area.
- The length of the area.
- Number of hosts.
- Number of BSs.
- Number of APs.
- Service Types (e.g., voice).
- Host Types (e.g., pedestrian).
- Session type (e.g., traffic models).

The decision functions that were taken into consideration in our simulation were:

- WiMAX only (no AP), in case Wi-Fi is not working (reference function).
- No Decision Function (no DF) – meaning that if Wi-Fi exists in the connectivity range the host will automatically connect to it.
- Decision Function 1 (DF 1 SS) – Including only the signal strength parameters.
- Decision Function 2 (DF 2 slots) – In addition to the signal strength, it also considers QoS in the WiMAX.
- Decision Function 3 (DF 3 battery) – In addition to DF 2, taking into account the host's battery.
- Decision Function 4 (DF 4 Tin) – Our decision function (with user mobility).

The four decision functions above represent an evolution of decision function until the system-wise entity is reached.

The mobility module is in charge of updating the host's position. We decided to model mobility based on the "Random Waypoint" algorithm [16], which randomizes a new position and wait time interval in each phase.

Finally, the parameters we are checking when comparing the simulation types are:

- The number of choices made by the Decision Function.
- The load balancing on Wi-Fi and WiMAX cells.
- The host's deployment and utilization of the network.
- The average battery usage.
- The QoS of each application over the WiMAX network.

An example of one of the scenarios of the simulation can be viewed in Figure 4.

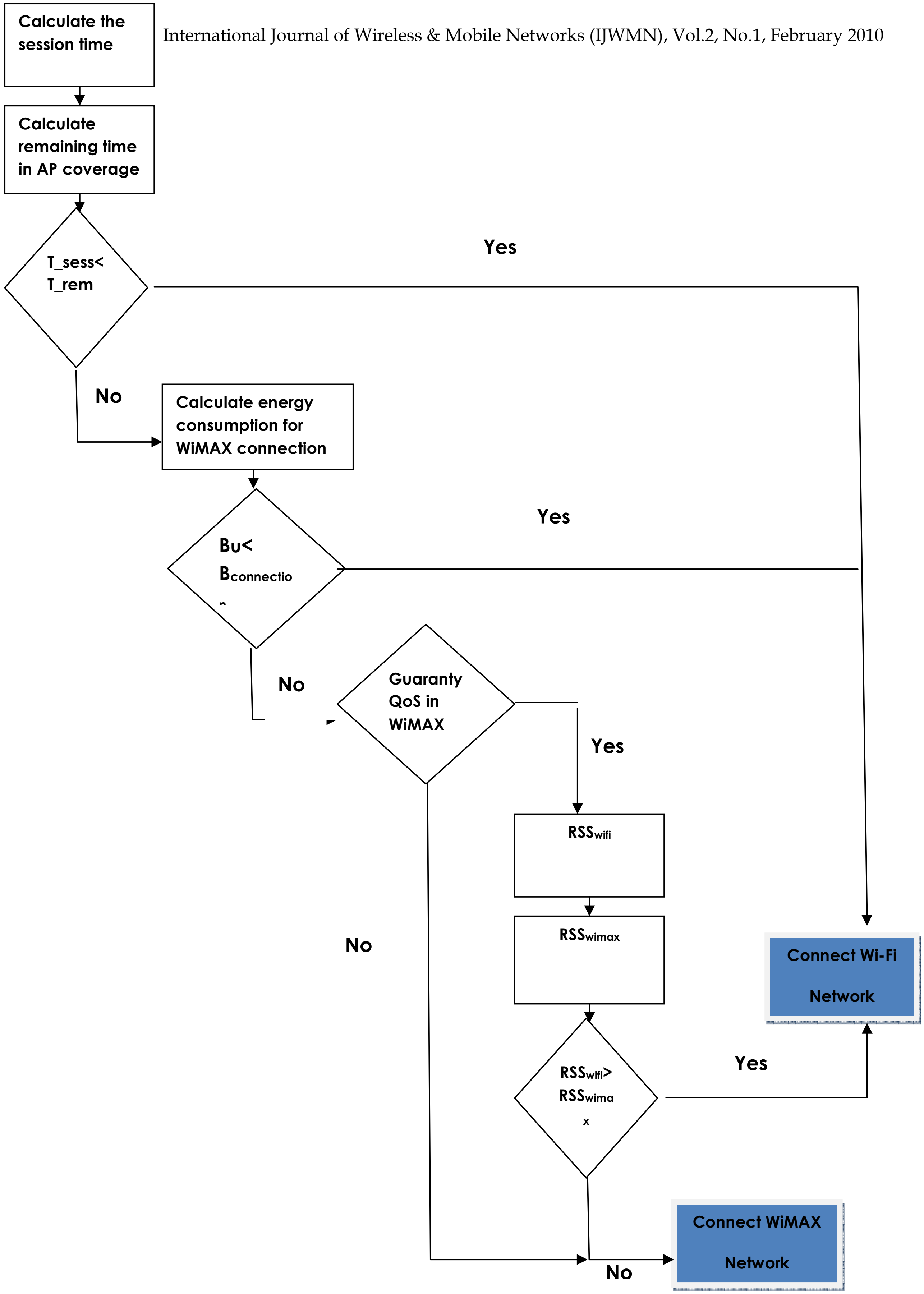


Figure 3. The Decision Function Flow.

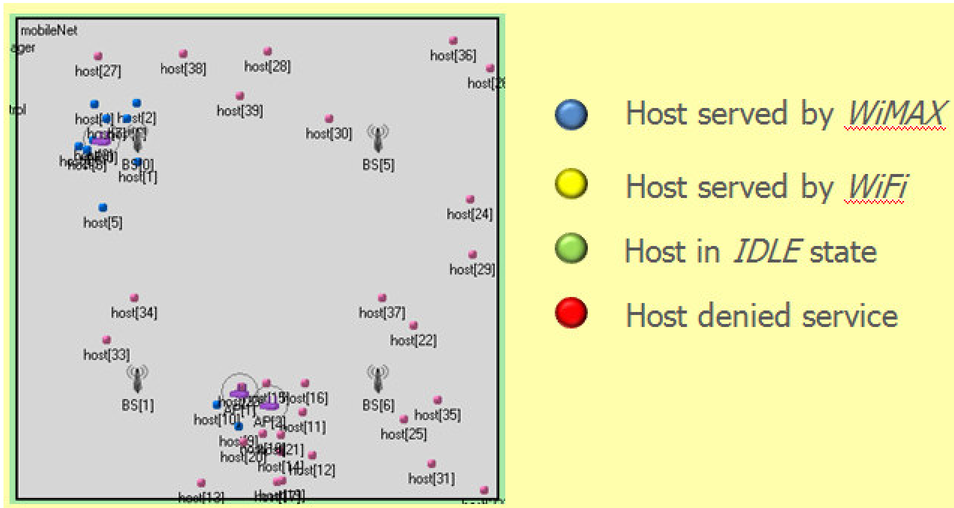


Figure 4. Simulation Example.

5. RESULTS

First, we wanted to understand the effect of each part of our system's function. Thus, we simulated a number of DF types. The parameters of the simulation were:

- Width of the area = 4 km.
- Length of the area = 4 km.
- Number of hosts = 300.
- Number of fixed BS (802.16) in the area = 4.
- Number of fixed APs (802.11) in the area = 24.
- Three Service Types: voice, data, and video.
- Two Host Types: 66% Pedestrian ("0–3 km"), and 33% Vehicles ("50–80 km").
- Each session type has its probabilistic function: Interrupted Renewal Process (IRP2) for video, Interrupted Poisson Process (IPP4) for data, and Interrupted Deterministic Process (IDP) for voice [11].

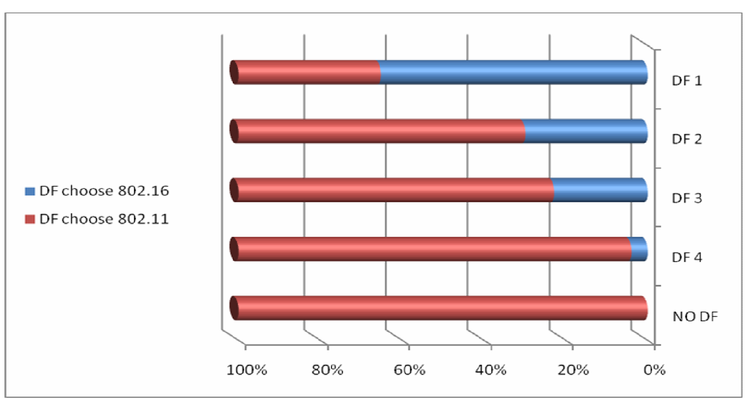


Figure 5.Comparison of Wi-Fi and WiMAX choices.

Each of the above function types (DF 1–4) run on different seeds. It is important to mention that comparisons were made between the types on the same seed. We fixed the positions of the BSs in the following coordinates – (100,100), (100,300), (300,100), and (300,300), and predefined the positions of all APs to simulate shopping centers. The statistics have been retrieved from averaging all runs of the simulation.

The relation between the number of times the network entity chose to connect a user to a Wi-Fi or WiMAX while the user is in a dual coverage area is described in Figure 5. From this figure we can see that, as expected, by adding more information to the system function, the usage of Wi-Fi increases.

We were interested in identifying the improvement of system performance by means of load. In order to find the corresponding statistic we calculated the number of dropped packets as a percentage of the number of total packets sent to the AP. Calculating the percentage, as opposed to the raw value, is

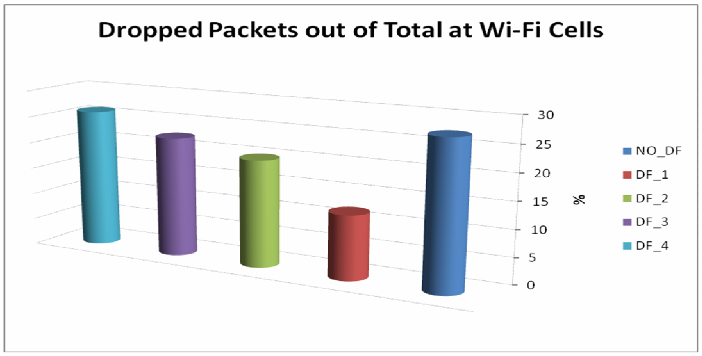


Figure 6. Percent of dropped packets out of total packets to Wi-Fi.

essential due to the different number of sent packets to the Wi-Fi in the different simulations. The percent of dropped packets is represented in Figure 6. In the figure we can see that DF1 results in the best percentage. These results could not be considered alone; they come across with Figure 5, which shows that as we add more information to the system function it creates more load on the APs, and therefore, more dropped packets. This figure also can serve as an indicator for what DF function we need to choose with respect to the desired load on the Wi-Fi cells.

Examining the percent of blocked sessions out of the total number of sessions in the hosts also yields interesting results. The averaged percent of blocked sessions among all hosts in the system is shown in Figure 7. The results show once again that increasing the knowledge of the system produces fewer blocked sessions and, therefore, gives improved performance, sometimes significantly better.

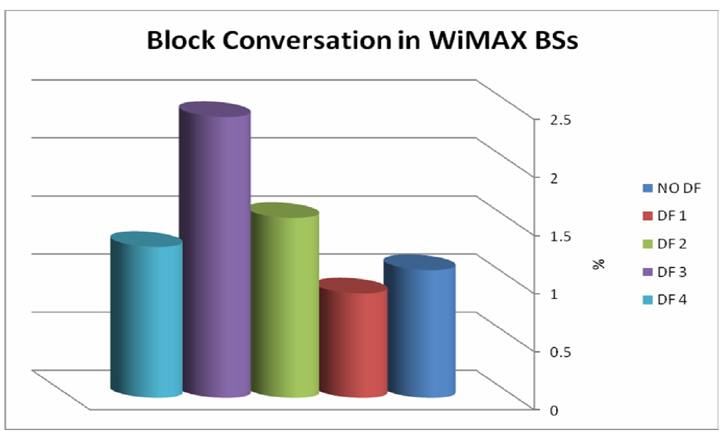


Figure 7. Percentage of blocked sessions out of total sessions to WiMAX.

An important aspect of a wireless communication system is the battery consumption aspect. Prolonging the battery lifetime is a major issue in the design of wireless technologies. Moreover, bad performance may lead to a large number of dropped and blocked packets that will have to be transmitted more than once. The average battery usage among all hosts in the system is described in Figure 8. We can see from the figure above that, on average, the case of WiMAX only (with no APs) gives the largest battery usage (rightmost column), meaning the hosts use the largest amount of battery energy; the leftmost column belongs to the case of the full system function that considers all the parameters, giving us the best battery utilization. However, we also have to refer to the 2nd best result, which, in contradiction to our initial expectation, corresponds to the simulation with no use of decision function. This can be easily explained by considering the results of Figure 5 that shows us how the case of "No DF" always chooses Wi-Fi. However, the case of DF 4 conducts fewer Wi-Fi sessions than the case of "No DF" and still outperforms it.

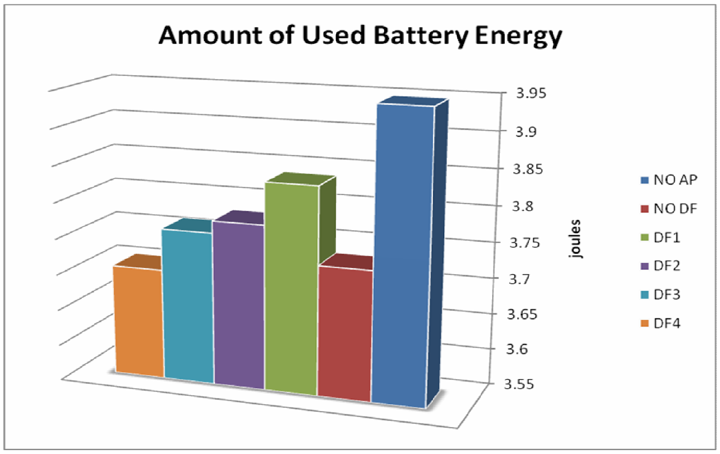


Figure 8. Average amount of used battery energy.

Since we also focus on the WiMAX part of the simulation, it is very important to follow the performance of our three implemented algorithms in the WiMAX uplink scheduler. We have checked the performance of each algorithm according to the QoS requirements of the three kinds of applications (Voice, Video, and Data). Since the voice application has the highest priority, the BS almost always has enough slots to allocate to voice sessions. Moreover, the voice application cannot tolerate connection with any percentage of lost bits due to its strict QoS requirement. When the BS does not have enough slots to allocate to a voice connection, this connection will disconnect from the BS. Therefore, starting with video application, we can see in Figure 9 the average percent of lost bits in video sessions. We observe that the maximum percent of lost bits is only 2.5 and in most cases it is much less. According to the results we can conclude that the video application can match its QoS requirements well, even when the BS is heavily loaded. From Figure 10 we conclude that the lost data bits percent is lower than the video percent of lost bits. This result is as expected since the data application is less delay sensitive than the video application and also because the maximum delay of a data packet can be up to 1 second according to our algorithm.

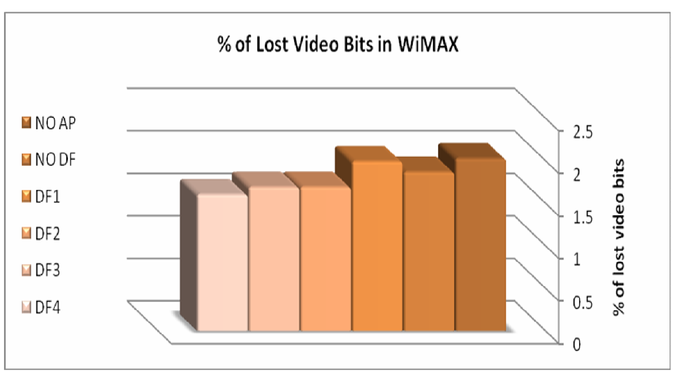


Figure 9. Percent of lost video bits in WiMAX.

Finally, we checked the average delay of data packets, in order to measure the time from the moment the BW request has been sent, until the scheduler, which resides in the BS, allocates bandwidth for this request and sends the BW response. From Figure 11 we can see that the average delay of the data packets is much less than the upper delay boundary its scheduler algorithm permits (1 second). Even in the NO

AP scenario, when the BSs are heavily loaded, the maximum average delay is still small enough (0.09 seconds), i.e., we have another indication that our algorithm handles the data sessions well and meets their QoS requirements. Furthermore, the NO AP columns (when the entire load is on WiMAX cells) has a very similar average delay as in the other scenarios where the load is shared between WiMAX and Wi-Fi cells, i.e., the data algorithm handles the data sessions well even when the BS is heavily loaded.

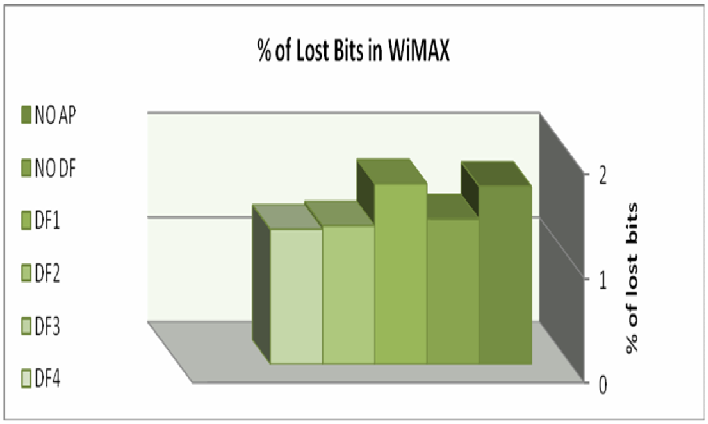


Figure 10. Percent of lost data bits in WiMAX.

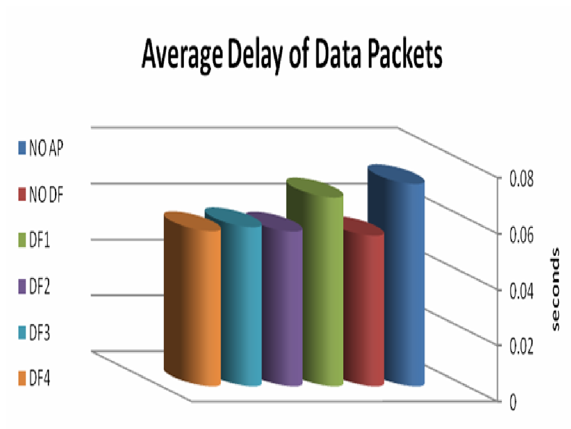


Figure 11. Average delay per BS.

6. Conclusions and Future work

We define a new system-wise entity that is activated when a user is in an area with overlapping access technologies and needs to decide the best technology to be used, where the entity performs technology selection in order to optimize the overall system performance metric in terms of throughput and capacity limitation. Our simulation results validate the efficiency of our method and show that it is also applicable to other combinations of access technologies. Moreover, our simulation results show improvement in the following network components: battery usage, performance, and load balancing, while the network is a combination of Wi-Fi APs with same coverage of WiMAX BSs.

The statistics show that the system function enables us to control the influence of Wi-Fi existence in the network. We can now ensure that each application gets appropriate service that fulfills its QoS requirements by getting an accurate report of each application's connection quality.

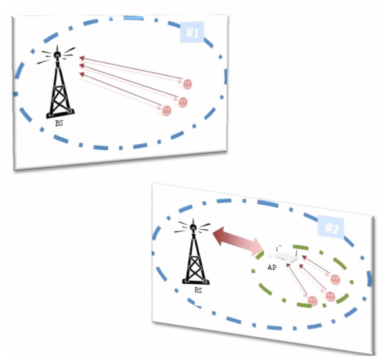


Figure 12. Wireless AP.

As for future work, an interesting issue to investigate is either fixed or mobile APs (wireless AP) that retrieve their bandwidths (hosts connecting to the AP) from the BS. Another way to think of those APs is as of super hosts. Moreover, we want to investigate the differences between the case of a wireless AP servicing several hosts and several hosts connecting directly to the BS (see Figure 12). Comparison of the above ideas with 802.16j can be an interesting issue for future work.

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