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INVESTIGATION OF BANDWIDTH ALLOCATION BASED ON RAT SELECTION IN A WIRELESS HETEROGENEOUS NETWORK FOR SMART HOME APPLICATION

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ABSTRACT

Smart homes have gained a lot of attention in recent years. People are looking forward to receiving an opportunistic network, where they can gather communication devices within a wireless heterogeneous network. The most important issue in a wireless heterogeneous network is to manage bandwidth, due to the scarcity of this resource in wireless links, compared to wired networks. Bandwidth management inefficiency may result in an unsatisfactory performance of a network. This paper investigates bandwidth allocation based on Radio Access Technology (RAT) selection in a wireless heterogeneous smart home environment that integrates different RATs considered in the study, which are Bluetooth, cellular 3G, and Wi-Fi. The nodes/users in a smart home are served through a RAT that best fits the service requirements; with adequate bandwidth that guarantees Quality of Service (QoS) requirements. We will demonstrate the comparison between the bandwidth occupancy of each RAT using two types of service admission procedures. From the results, the bandwidth occupied by different RATs show a variation distribution depending on the service admission control procedure used. We advocate the notion of bandwidth allocation with adequate bandwidth for service application requests as a criterion to quantify the state of balance in future heterogeneous multi-RAT environments.

Keywords: *Radio Resource Management, Bandwidth, RAT Selection, Heterogeneous Wireless System, Smart Home*

1. INTRODUCTION

Driven by advances in electronic devices, such as notebook computers, smartphones, digital cameras, music players, handheld games, camcorders, and many other consumer electronic devices, the requirement for a smart environment solution is taking shape in many of the spaces of our daily lives. The smart environment concept is defined as a group of devices that are interconnected in a network to make the lives of users more comfortable [1, 2]. These devices are able to make intelligent decisions - without human intervention. Examples of smart environments include smart homes, smart buildings, and larger environments like airports, hospitals, university campuses, etc. In previous research works, these smart environments have been proposed and designed in a variety of disciplines. The majority of these works focused on sensor devices embedded in homes; where there was a control unit that would interpret those sensors. For example, Smart Home Automation [3] aimed at reducing the overall electrical energy consumption per household, in [4], Smart Home Applications were designed for disabled people. Meanwhile, the proposed smart home in [5] was equipped with a Wireless Sensor Network (WSN) and Radio Frequency Identification (RFID) to identify motion within an environment to perform an action; for example, to turn lights on when someone entered a room and turn them off when they exited. In the future, an opportunistic network regards the rapid penetration of embedded devices within home surroundings, as well as the successful deployment of a number of Radio Access Technologies (RATs) that overlap within the same serving cell area. This future oriented technology requires efficient radio resource management that includes resource allocation, scheduling, and monitoring.

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Radio Access Technology (RAT) in a smart environment consists of a heterogeneous mix of wireless interfaces, such as UMTS, GSM, WLAN, WiMAX, cellular 3G, peer-to-peer (P2P), etc. An efficient radio resource management strategy, which can utilize and fairly share radio resources, is needed to satisfy the smart home requirement in terms of user experience, as well as for a digital economy environment. Radio Resource Management (RRM) techniques are basically used to maximize the performance of network throughput [6]. Resource management schemes have been presented in many ways, such as a call admission scheme, channel allocation, scheduling, transmission rate control, a priority based service, handover schemes that control access port control, and bandwidth allocation schemes [7-9].

Bandwidth is considered to be the most expensive resource or component of a network; as it is a benchmark that is used to evaluate network performance. Proper bandwidth allocation will increase the performance of a network [10, 11]. With regards to the importance of this resource, this paper will focus on bandwidth allocation for a smart home environment. There are several issues that need to be considered when allocating the bandwidth such as; each service request has their own preferred RAT with appropriate level of bandwidth that must be assigned to the requesting users to reach the satisfaction level of communication. However, it may not be always possible for the service to obtain their preferred RAT as well as bandwidth and that RAT may no longer be preferred in this situation. Home networks provide users with access to the Internet through heterogeneous connectivity technologies, such as IEEE 802.11x in a Wireless Local Area Network (WLAN) or Wi-Fi, 3G cellular, and Bluetooth. These network access technologies will be considered within the investigation of bandwidth allocation strategies in a smart home environment.

2. METHODOLOGY

A numerical simulation was carried out using MATLAB to demonstrate bandwidth allocation for a smart home application. The simulation was run for 1 hour, because this was considered to be adequate time for modelling network traffic, in order to analyze the variations in occupancy for each network technology within a smart home environment. Twenty nodes were involved that represented the number of users in a smart home environment, for handheld games, a camcorder, a printer, and several smartphones. This smart home network simulation was used as an example of communications within a small network integrated WLAN, Bluetooth, and 3G cellular; regardless of passive sensors, such as smoke detectors, motion sensors, gases, and humidity; as presented in other studies [1, 2, 12-15].

Table 1 shows the pseudo code for the Service Admission 1 procedure. When a node requests voice or video call services, Wi-Fi becomes both the priority and preferred network. However, if there is not enough spare Wi-Fi bandwidth to accommodate or the device is not within the Wi-Fi's coverage, it will overflow for cellular 3G. If the node requests file transfer services, this request will be assigned to Bluetooth as the first choice of RAT selection. However, this will depend on Bluetooth coverage and the pairing node between transmit and receive nodes. Full admission scheme details are shown in Table 1.

Table 1: Pseudo Code for Service Admission 1 Procedure

```
For i = 1: length (node) Do
    If incoming_call = voice_call || incoming_call = video_call
Then
            Try Wifi
            If WiFi_coverage == 1 && free_slot == 1 Then
                If Wifi_Bandwidth == 1
                Accepted to Wifi
                Endif
            Elseif
            Try Cellular
             If Cellular_3G_coverage == 1 && free_slot  =1
Then
                IF Cellular_3G_Bandwidth ==1
                Accepted to Cellular_3G
                Endif
            Else
            Task Terminated
            Endif
    Elseif
    Try Bluetooth
        If pairing_nodes==1
          IF Bandwidth_Bluetooth ==1 && free_slot==1
          Accepted to Bluetooth
          Endif
        Elseif
        Try Wifi
        If WiFi_coverage == 1 && free_slot == 1 Then
          If Wifi_Bandwidth == 1
          Accepted to Wifi
           Endif
        Elseif
        Try Cellular
         If Cellular_3G_coverage == 1 && free_slot ==1
Then
              If Cellular_3G_Bandwidth ==1
              Accepted to Cellular_3G
              Endif
         Else
         Terminate task
         Endif
```

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A comparison was made with another service admission procedure, known as Service Admission 2 (as shown in Table 2). In this scheme, when a user requests a video call, Wi-Fi becomes the service preference, and if a user requests a voice call, it will go for 3G cellular and file transfer will be assigned to Bluetooth. This procedure is a traditional scheme, as the cellular network would always be the first choice for voice services in a usual admission control policy

Table 2: Pseudo Code for The Service Admission 2 Procedure

```
For i = 1: length (node) Do
    If incoming_call = video_call Then
            Try Wifi
            If WiFi_coverage == 1 && free_slot == 1 Then
                If Wifi_Bandwidth == 1
                Accepted to Wifi
                Endif
            Elseif
            Try Cellular
            If Cellular_3G_coverage == 1 && free_slot ==1
Then
                If Cellular_3G_Bandwidth ==1
                Accepted to Cellular_3G
                Endif
            Else
            Task Terminated
            Endif


    Elseif incoming_call = voice_call Then
            Try Cellular
            If Cellular_3G_coverage == 1 && free_slot ==1
Then
                If Cellular_3G_Bandwidth ==1
                Accepted to Cellular_3G
                Endif
            Else if
            Try Wifi
            If WiFi_coverage == 1 && free_slot == 1 Then
                If Wifi_Bandwidth == 1
                Accepted to Wifi
                Endif
            Else
            Task Terminated
            Endif
    Else (incoming_call=file_transfer)
            Try Bluetooth
            If pairing_nodes==1
            If Bandwidth_Bluetooth ==1 && free_slot==1
            Accepted to Bluetooth
    Endif
        Elseif
        Try Wifi
        If WiFi_coverage == 1 && free_slot == 1 Then
          If Wifi_Bandwidth == 1
          Accepted to Wifi
           Endif
        Elseif
        Try Cellular
         If Cellular_3G_coverage == 1 && free_slot ==1
Then
              If Cellular_3G_Bandwidth ==1
              Accepted to Cellular_3G
              Endif
          Else
          Terminate task
          Endif
Endfor
```

This simulation focused on three important RAT parameters, which were (i) maximum bandwidth, (ii) RAT capacity, and (iii) effective coverage for each RAT. The traffic model adopted for the simulation is shown in Table 3. A total bandwidth pool of 3 Mbps per connection in Bluetooth 2.1 (adopted as the IEEE 802.15.1)[16, 17], 54 Mbps in Wi-Fi refers to IEEE 802.11g[18], and 7.2 Mbps in 3G High Speed Downlink Packet Access (HSDPA)[19, 20] was used. Bluetooth clearly had an advantage in terms of high data rates and the support of a wider range of traffic types over Zigbee. Moreover, the Bluetooth network's access was fast whilst always being awake and constantly aware [21]. Table 4 shows the types of network services used in the simulation a file transfer, and voice and video calls. This smart home environment focuses on bandwidth allocation based on these 3 different types of network service. Each incoming network service demands a preferred bandwidth; depending on the type of call (as shown in Table 4). Service request arrivals are assumed to be Poisson with a maximum duration of 30 seconds for each of voice and video call, and 2 seconds for file transfer. This simulation assumed that when the bandwidth is sufficient, both packet delay and jitter network parameters are very low. Therefore, real time transmissions for voice and video calls work well in terms of user satisfaction.

Table 3: Traffic Model Adopted for the Simulation

Radio Access Technology(RAT)	***Total bandwidth (Mbps)***	***Network Capacity***	***Effective coverage (m)***
Bluetooth 2.1 [17]	3	7	10
WiFi [20]	54	50	100
Cellular 3G [22]	7.2	100	1000

Table 4: Type of Call With Bandwidth Requirement

Services	***Bandwidth requirement (Kbps)***	***Maximum call duration***
Video	500	30 seconds
Voice	500	30 seconds
File Transfer	500	2 seconds

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In this simulation, 20 nodes were randomly placed within a 15 x 15 m area (as shown in Figure 1). The 20 nodes were a combination of passive and active nodes. An example of a passive node is a wearable smart medical device. When combined with a mobile phone or tablet, glucose monitors can automatically update the user's logbook using a smartphone application; or blood monitoring implants in the patient's body using Bluetooth technology. The device transmits data to the smart phone for tracking purposes. Active nodes are those used in wireless handheld devices, wireless laptops, printers, or smartphones. The node mobility scenario is generated randomly based on a random way point model; where a mobile node moves to a new position, pauses there for a period of between 0 to 3 seconds, and then moves to another position. Future work will consider performance measurements between both mobile and fixed nodes.

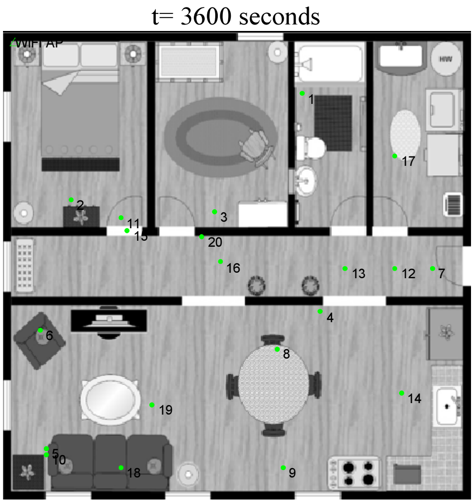

Figure 1: Simulation Area for A Smart Home Environment

3 RESULTS AND ANALYSIS

3.1 Simulation Results for the Service Admission 1 Procedure

Figure 2 shows the bandwidth used during 1 hour of simulation for each network access technology. Meanwhile, Figure 3 shows the number of nodes involved in the simulation. Figure 2 shows that there is a small amount of bandwidth used for Bluetooth technology throughout the simulation, and the communication occurred only at a certain times; because Bluetooth functionality for the considered smart home environment is limited to file transfer only. Besides, this could have been due to the non-existence of pairing nodes to do the file transfer between. Therefore, the bandwidth usage for Bluetooth was less than that of other RAT.

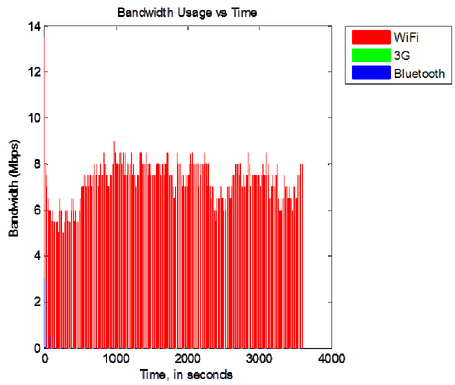

Figure 2: Bandwidth Usage During 1 Hour of Simulation for 20 Mobile Nodes

In the service admission 1 procedure, the service request for voice and video calls was assigned to Wi-Fi as the RAT priority selection. From the results shown in Figure 3, the number of active nodes was dominated by Wi-Fi users within the smart home area. This was due to the possibility that all nodes in this home had access to Wi-Fi; and therefore, more video and voice calls were admitted to the Wi-Fi network in this procedure.

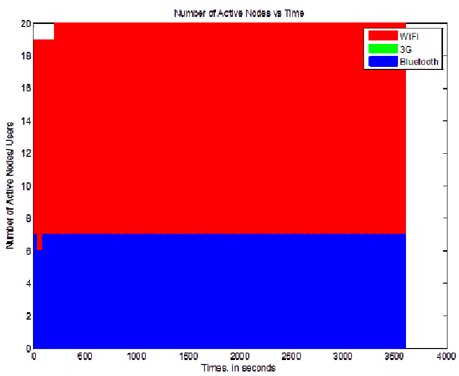

Figure 3: Number of Active Nodes Doing the Communication

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3.2 Simulation Results for the Service Admission 2 Procedure

The results for the Service Admission 2 procedure simulation are different. In this procedure, the voice call service was assigned to cellular 3G as the preferred network when choosing the RAT; thus resulting in more bandwidth usage for cellular 3G (as shown in Figures 4 and 5).

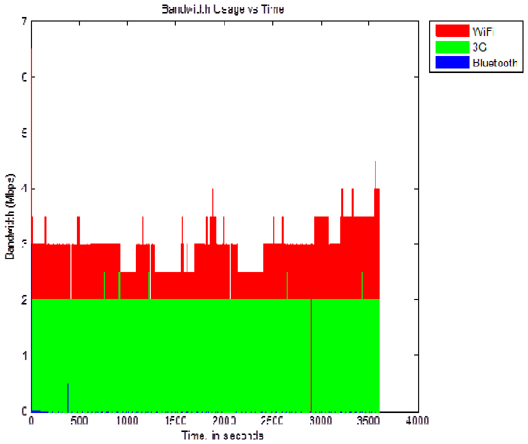

Figure 4: Bandwidth Usage During 1 Hour of Simulation for 20 Mobile Nodes

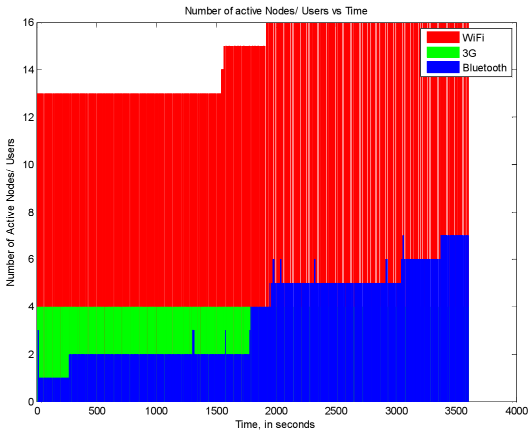

Figure 5: Number of Active Nodes doing the Communication

The measurement of bandwidth occupancy under different RATs for both network service admission procedures is shown in Figure 6. As a comparison, the bandwidth occupied by Wi-Fi users was reduced from 99.98% (in network service admission 1) to 59.86% (in network service admission 2). Meanwhile, there was also an increment of cellular 3G bandwidth occupancy from 0% (in network service admission 1) to 40.08% (in network service admission 2) in the simulation. For Bluetooth bandwidth occupancy, there was little difference between both procedures. The small occupancy of bandwidth by Bluetooth in this simulation was probably due to Bluetooth needing to be paired within the coverage (10 m) to transfer files; thus, the nonexistence of pairing nodes will not allow communication to occur. Furthermore, the mobility of the nodes in the house makes it harder for the nodes to use Bluetooth.

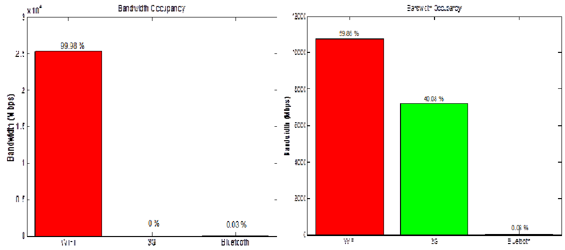

Figure 6(a) Call Admission 1 Procedure *Figure 6(b) Call Admission 2 Procedure*

Figure 6: Bandwidth Occupancy for Each RAT

4. CONCLUDING REMARKS, FUTURE WORKS AND CHALLENGES IN FUTURE SMART HOMES

This paper has demonstrated the preliminary results of bandwidth allocation simulation using service based RAT selection in a wireless heterogeneous smart home environment. In bandwidth allocation, it is important to adjust and maintain the QoS requirement at a satisfactory level, at an adequate bandwidth. In this simulation, each incoming request for all services by nodes was served with a satisfactory bandwidth. In RAT selection, it is also important to achieve a minimal cost of communication, as cellular 3G use is expensive. Bluetooth RAT is limited in terms of a communications capability that could not meet the requirements of all services. Bluetooth cannot accommodate real-time communications, such as voice and video calls, as well as internet access. In future opportunistic networks, client' nodes can help other clients to achieve internet connectivity in a peer-to-peer way via Bluetooth Personal Area Network (BPAN) connections; by acting as intermediate entities in a multi-hop (possibly heterogeneous) path towards the internet. This situation requires cooperation among heterogeneous nodes using context awareness capabilities.

In order to build an intelligent resource management algorithm for a wireless

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heterogeneous network, there is a need for a whole analyzing of the pattern at the resource level. Intelligent resource management will provide the most appropriate radio resources and wireless services to those needs, and guarantee better communications in the future. A significant amount of work remains to be done in order to prepare an efficient bandwidth management and the management of other network resources; such as power level for data transmission, throughput, and interference management.

A wireless heterogeneous network in an area will see a more efficient use of the RATs available. For example, node A demands a video call, but has no access to WiFi and refuses to use cellular 3G as it is too costly. Using location awareness capabilities, this node detects in its short range area that node B is in Wi-Fi coverage. With some negotiation, node B establishes a connection with node A, and node B relays the required packet data to node A through a short-range cooperation using Bluetooth (for example). Therefore, node A can complete the video call using WiFi; even though it is not in direct coverage. This will reduce costs over using a cellular 3G data plan. In this situation, the individual node is required to obtain information about the neighbour node's capability in order to relay packets on behalf of other nodes and deliver data through the network. This needs to be taken into account in the design of resilient and robust radio resource management within a smart home system.

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