A User-Centric Network Architecture for Sustainable Rural Areas

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Abstract. Heterogeneous networks offer interesting solutions to problems encountered in user-centric network architecture. Encompassing various communication technologies, they offer great potentials for addressing some of the challenges that ICT based remote services face. In this work, we focus on their deployment in rural areas and developing countries. More specifically, we examine how heterogeneous networks can be used in a user-centric architecture to improve application interactivity, interoperability, and network utilization. Restrictions of each constituent technology cause the architecture to have an upper limit in supporting simultaneous interactive applications. To investigate these limits, and to identify potential enhancements, we study an interactive education model. The considered interactivity, facilitated by heterogeneous networks, is between clients in rural areas and servers in an urban area. The underlying model architecture involves several communication technologies such as WiFi, Ethernet, WiMAX, and UMTS. Several scenarios relevant to this architecture are simulated and analyzed. For each scenario, videoconferencing sessions are initiated with variant number of users. The performance of the architecture in terms of capacity and key QoS parameters such as delay variation, end-to-end delay, and packet loss is evaluated. The results show that for most typical situations, WiFi-WiMAX combinations outperform other integrations.

Keywords: Heterogeneous network, Network architecture, UMTS, WiFi, WiMAX.

1 Introduction

Part of the millennium development goals set by the United Nations can be met by delivery of socioeconomic services based on heterogeneous network architecture. However, in general, provisions of such services through such networks are not widely common in developing countries. On the other hand, in industrialized world, heterogeneous networks play an important role in providing improved socioeconomic services. For instance, cluster of school concept *ICTPD* has been implemented in New Zealand utilizing network and communication technologies. Videoconferencing (VC) based distance education model has been successful in Alberta, Canada by

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utilizing a high bandwidth broadband network, *Supernet* [1]. But for most developing countries, the benefits of similar types of projects are hard to be realized, as they lack the infrastructure needed for provision of fixed broadband technologies.

To resolve some of these issues, various solutions based on wireless technologies have been proposed and implemented for developing countries. For instance, *Daknet* is a WiFi-based system, which has introduced positive changes in rural areas [2]. It uses portable storage devices placed on vehicles as mobile access points to facilitate uploading, downloading, and synchronization of data. It focuses on providing Internet access and support for non real-time applications, such as e-mail, for rural areas. Only non real-time applications are supported as the project argues that in rural areas, people use non real-time network applications much more than real-time ones. While this may be true for some situations, to advance the quality of remote education, health and commerce services, interactivity is a requirement [3].

Another example is Long Distance WiFi based solution, *WiLD,* which has been deployed in India and Ghana to provide remote health and education services [3]. However, these networks experience highly variable delay and interference from external environment. Wireless mesh networks are able to extend the coverage area of developing regions [4]. But they face some fundamental issues when deployed in a larger area [3]. These include significant interference in overlapping cells due to a large number of access points. Another issue is the reduction in throughput as a result of increased hop length associated with an increasing number of low-gain omnidirectional antennas. Some studies have suggested the integration of WiFi-WiMAX for developing countries [5]. However, such approaches require custom-built radios and smart antennas.

Clearly, each solution has both positive and negative characteristics. As such, it does not seem feasible for any single communication technology to be able to provide an end-to-end sustainable solution that meets all of the interactivity and interoperability requirements. Each technology has its own pole capacity and QoS mechanisms, which make it appropriate for some particular applications and environments. To overcome the drawbacks of using one technology, heterogeneous networks offer promising solutions.

To discuss these ideas and potential solutions, the remainder of this paper is organized as follows. Section 2 discusses related work and establishes motivations for our work. Section 3 illustrates our proposed architecture. In Section 4 the simulation results for various scenarios used for examining and evaluating the proposed architecture are presented and analyzed. The last section concludes the paper and discusses our future works.

2 Related Work and Motivations

Related work to this study can be broadly divided in two categories. In one category, various network based solutions in context of rural area are discussed. The other one relates to provision of multimedia over heterogeneous networks. There is a growing interest from networking research community in utilizing different wireless and cellular technologies to provide education, health, and commerce based services in rural areas. Again, broadly speaking, these solutions can be classified into two main groups. The first one includes solutions based on 802.11 WLAN, 802.16 WiMAX and similar type technologies based solutions [2-5]. The second group consists of solutions based on cellular systems [6] and [7]. A third group of solutions can also be considered as the convergence these two types of technologies [8] and [9].

From a user point of view, the rising demand for multimedia traffic has opened up new interests in adaptive video streaming, videoconferencing and similar applications running over wireless and cellular networks. Delivery of on-demand video services in rural areas over 802.16 WiMAX networks has been studied in [10]. The study designs an extensive simulation model for H.264/AVC scalable video coding and investigates the system capacity and buffer-based congestion control algorithms. It also evaluates the performance of video streaming traffic in the context of WiMAX technology. The advantages of using 3G and particularly CDMA450 for rural areas have been discussed in [7].

Some of these studies have been expanded to design the necessary architecture to support video streaming [11]. However, the reported performance study only evaluates WiMAX networks through simulation. To complement that work, simulation analysis of video and voice traffic for different QoS classes in WiMAX is reported in [12]. Most of the published work in this area is concentrated on evaluating the performance of video streaming applications over heterogeneous networks. The majority of them then focus on WiMAX technology in the context of asymmetric multimedia applications such as video streaming. This paper expand on those works, in the sense that our research studies a heterogeneous network involving WiMAX, UMTS, WLAN, and Ethernet technologies. We also report on the performance analysis of some symmetric multimedia applications, such as VC.

VC is considered to be a highly effective tool in distance education [1]. Several VC based tele-education models for surgery have also been implemented in both industrialized and developing countries [13]. Essentially, four networking technologies are suggested for VC delivery. These include IP based networks, satellite communication systems, 3G systems, and other broadband technologies. Different VC applications use different architectures. Our work makes some novel contribution in understanding technological challenges in implementing VC over a heterogeneous network. This work also proposes an interactive education model over heterogeneous network and conducts the performance evaluation by studying behaviors of key network QoS parameters namely delay variation, end-to-end delay, and packet loss.

3 Proposed Architecture

Our proposed architecture is illustrated in Figure 1. In the proposed model, the conference participants of rural area are considered to be participating through 3G (UMTS), WLAN, or Ethernet. The linkage between them and the urban area is through an IP-based network. The conference participants in urban area can be using WiMAX or Ethernet. A SIP-based proxy server sits between the urban area and the IP backbone. All video and audio data from both parties are transmitted via this server. The overall architecture of the Rural Area Network (RAN) can be considered in three network-technology based clusters. These are the UMTS/3G cluster, the WLAN cluster, and the Ethernet cluster. The Urban Area Network (UAN) may also be categorized in two of such clusters, namely the WiMAX and the Ethernet clusters.

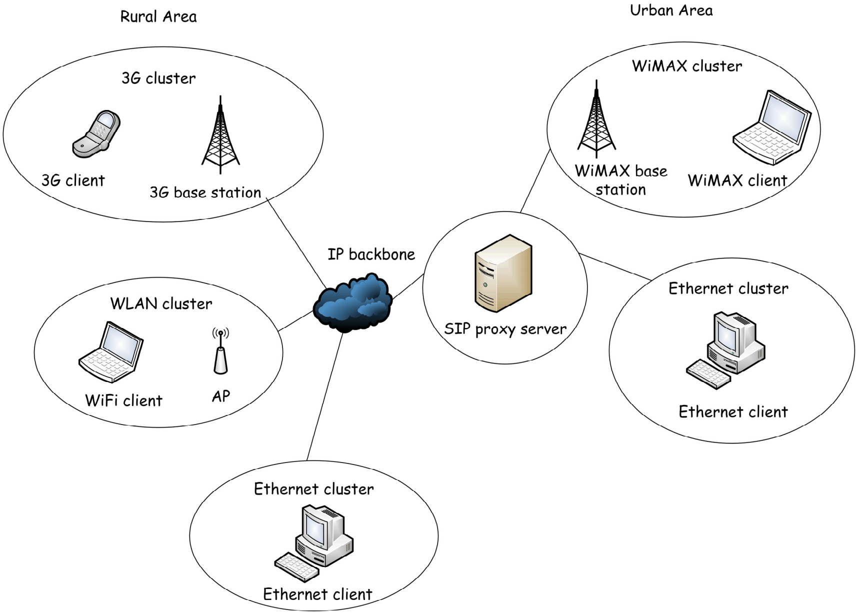

Fig. 1. Proposed model

Each RAN cluster has its own gateway that connects it to the IP backbone network, which in turn connects it to the proxy server of the UAN. The connection between the wireless access points and their wireless gateway nodes are considered to be provided by 45 Mbps Digital Signal 3 (DS3) links. The same links connect the wireless gateway nodes and the IP backbone network. A UMTS gateway node connects the UMTS GPRS support node (GGSN) to the IP-backbone network through a DS3 link. The gateway nodes connect UAN clusters to RAN through an IP backbone network.

Several architectures are suitable for VC applications. Peer-to-Peer (P2P) architecture can be used in a two-party VC session. In such architecture both participant can send data to each other directly. For a multi-party VC session, both P2P and server/client (S/C) based architecture are suitable. In a multipoint P2P VC session, users relay video to each other. On the other hand, in an S/C-based architecture, at first, the participants upload video to a server and then the server sends the video to the receiver. The proposed architecture is modeled over S/C based architecture. Figure 2 represents the architecture.

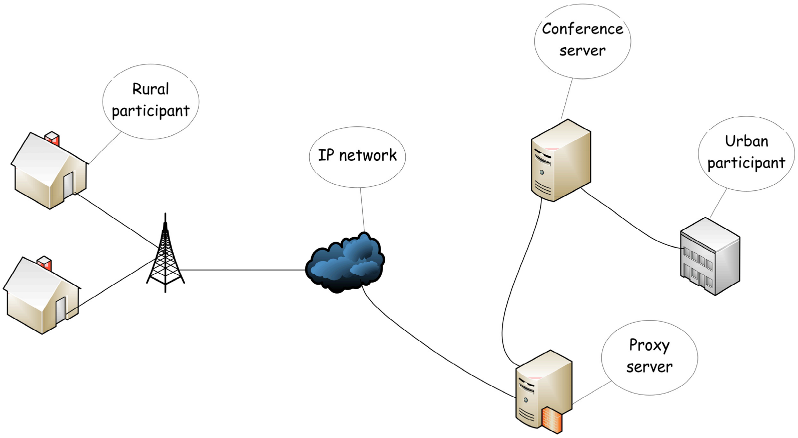

Fig. 2. Videoconferencing architecture

A number of VC applications are available depending on different architecture, bandwidth to data size. Bandwidth threshold and suitable video/audio packet size for several VC applications are analyzed in [14]. After comparing specifications of our proposed model with available VC applications, V see is selected. In terms of bandwidth and available user data rate, this application appears to be the most suitable one for this model. G.723.1.5.3k, which is the recommended codec for videoconferencing, is used for audio transmission. This codec has a frame size of 30 msec and coding rate of 5.3Kbps, with a payload size (*PL*) of 159 bytes. Table 1 summarizes the VC specifications.

Table 1. Videoconferencing specifications

Attributes	Values
Video frame rate per second	30
Video frame size (byte)	600
Video type of service	Differentiated service for Interactive multimedia (EF)
Audio codec	G.723.1.5.3k
Audio payload size (byte)	159
Bandwidth threshold (Kbit/s)	50

4 Result Analysis and Discussions

Multiple iterations of simulation were carried out to analyze the behavior of designed model from different perspectives. The system capacity is assessed for different types of traffic, the quality of video and voice transmissions are investigated ranging from a few to a large number of simultaneous participants. The analyses are discussed in detail in the following subsections.

4.1 Designed Scenarios

In the first scenario, two participants join the conference from each cluster of RAN. For instance, there are two participants in the UMTS cluster, one of them is in a conference with an urban participant located in the Ethernet cluster, and another participant of the same cluster is in a conference with an urban participant from the WiMAX cluster. In the same manner, participants from the Ethernet and the WLAN cluster join the conference with an urban participant.

Several other scenarios are designed with a variant number of simultaneous participants. In the second scenario, the number of participants is increased to twenty in each RAN cluster. For example, in the UMTS cluster, altogether, there are twenty participants. Ten of them are in a conference with an urban participant from the Ethernet cluster and ten other participants are in a conference with an urban participant from the WiMAX cluster. Both WLAN and Ethernet cluster support same number and type of conference. To elaborate, the urban participant located in the WiMAX cluster in UAN initiates a VC session with ten participants from the Ethernet cluster, ten participants from the WLAN cluster, and ten participants from the UMTS cluster of RAN.

In the third scenario, the number of participants is reduced to ten resulting in an equal number of participants in each RAN cluster for each urban user. In the fourth and the fifth scenario, the number of participants are reduced to eight and six respectively. Each VC session follows a specific naming convention, which is the name of RAN cluster of the participant followed by the name of the UAN cluster of the participant. For instance, the conference between a participant from the UMTS cluster of RAN and an urban participant from the WiMAX cluster is termed as UMTS-WiMAX pair/conference/transmission.

4.2 Performance Analysis

Performances for both video and voice transmissions of all VC sessions are tested against each scenario in terms of delay variation, end-to-end delay, and packet loss. Delay variation is the variance among end-to-end delay for all packets. End-to-end delay is calculated based on network delay, encoding delay, decoding delay, compression delay, and decompression delay. The acceptable performance values for these parameters are taken from [15]. Table 2 represents these values.

Table 2. Acceptable performance values for QoS metrics

Application	Metrics	Acceptable performance level
Video transmission	Packet end-to-end delay Delay variation Packet loss	< =150 msec <= 30 msec <=1%
Voice transmission	Packet end-to-end delay Delay variation Packet loss	<= 150 msec <=1% <=30 msec

Video traffic: In the first scenario, with three participants in each conference cluster, two in RAN side and one in UAN side the model achieves the acceptable performance level. Table 3 illustrates the values of each performance metrics received from the conference between three separate clusters of RAN and the Ethernet cluster of UAN. The conference between WiFi-Ethernet cluster show better performance than other cluster conference in terms of packet loss.

In case of conference between RAN clusters and the WiMAX cluster in UAN, the WiFi-WiMAX and the Ethernet-WiMAX conference experience insignificant packet loss. Other performance parameters such as end-to-end delay and delay variation also show a value within acceptance level. However, the participants in UMTS-WiMAX conference experience a higher packet loss than the former two. Similarly, end-to-end delay and delay variation exhibits a much higher value, which are 120 -220 msec and 1-14 msec.

In the next scenario, the number of participants in each conference cluster is increased to ten. Therefore, each urban participant is in a conference with thirty other simultaneous participants residing in different technologies. The model capacity is investigated in this stage of simulation. In case of UMTS-Ethernet conference, only one out of ten is able to join the conference. Although, all participants under the WiFi and the Ethernet cluster are able to join the conference and receive video data, the quality of received transmission varies. In case of conference with the urban user in the WiMAX cluster, seven out of ten participants in the Ethernet cluster are able to receive video transmission data. In case of participants in the WiFi cluster, only six out of ten are able to receive data successfully and two out of ten transmissions are successful in case of users in the UMTS cluster. However, the quality of received data for all users degrades drastically.

In terms of transmission quality, delay variation and end-to-end delay show insignificant difference from the previous scenario. However, users experience significant packet loss. Most of the users in the Ethernet cluster in RAN experience 6.67% to 13.3% packet losses. In case of WiFi-Ethernet conference, packet loss varies between 13% and 26%. Similarly, UMTS-Ethernet conference experience huge packet losses. Likewise, all conferences with the participant from the WiMAX cluster experience a significant amount of packet loss.

Table 3. Simulation results for RAN clusters – UAN cluster (Ethernet) conference

Conference type	Metrics	Resulting value
Ethernet-Ethernet	End-to-end delay Delay variation Packet loss	1.3 msec 1.5*10-4 µs 0.1 to 0.2%
WiFi-Ethernet	End-to-end delay Delay variation Packet loss	5.7 to 5.8 msec 0.15 to 0.2 µs 0%
UMTS-Ethernet	End-to-end delay Delay variation Packet loss	110 to 120 msec 1 to 3 msec 0%

To explore the capacity of the network further, in the third scenario, the participant number is reduced to five in each conference cluster. Therefore, each urban user from the WiMAX and the Ethernet cluster are in conference with 15 simultaneous users respectively. This time the successful connection ratio and packet loss improves significantly. Packet losses for all Ethernet-Ethernet video transmissions reduce to 3.3% and 6.67%. Few users of WiFi-WiMAX conference experience no packet loss and others experience 3.33% packet loss. However, the Ethernet-WiMAX and the UMTS-WiMAX cluster still experience significant packet losses.

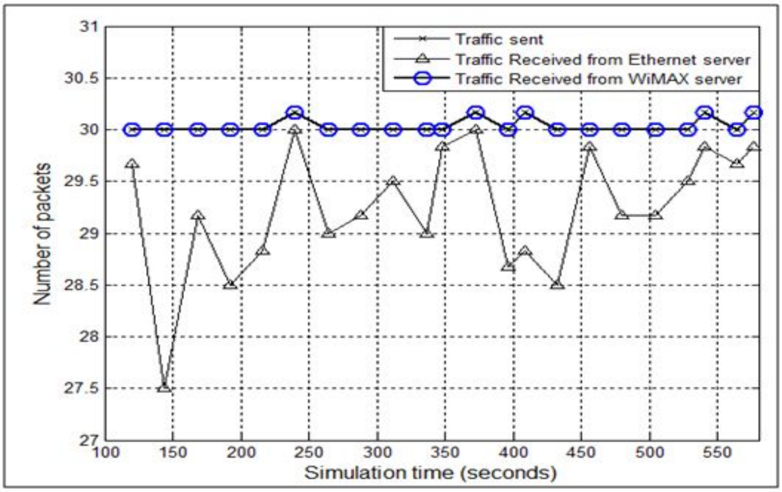

Fig. 3. Packet loss for WiFi clients

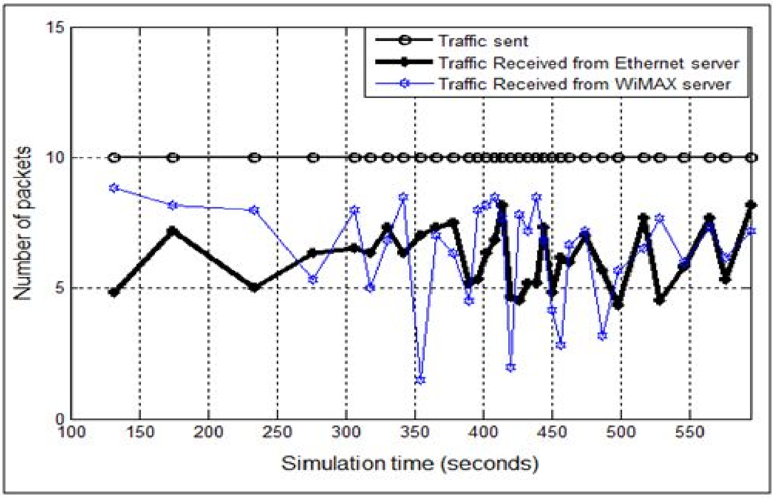

Fig. 4. Packet loss for UMTS clients

In the next scenario, the simulation is carried out with three simultaneous users in each conference cluster resulting in nine simultaneous RAN participants with one urban participant. As expected, the video transmission exhibits better results in terms of both capacity and quality. Two out of three participants from the WiFi-WiMAX cluster experience no packet loss. Participants in UMTS-WiMAX and Ethernet-WiMAX conference also exhibit better performance. Figure 3 and 4 show packet loss for the video transmissions in the third conference scenario. The figures clearly indicate that WiFi-WiMAX and UMTS-WiMAX conference show better performance than WiFi-Ethernet and UMTS-Ethernet conference. To summarize, the model can support up to ten simultaneous participants residing in different network technology in each VC session. In terms of video transmission quality, WiFi-WiMAX conference demonstrates better performance compared to other two conference clusters.

Voice traffic: The performance of voice traffic in VC is analyzed in this part. In the first scenario, the simultaneous users in the Ethernet-Ethernet conference experience the lowest packet delay variation (0.002~0.028 µs) compared to the WiFi-Ethernet (1.8~2 µs) and the UMTS-Ethernet (6.5~8.5 µs) pair transmissions. Participants under the WiFi-Ethernet cluster experience 80 ms end-to-end delay and the participants in UMTS-Ethernet conference undergo 130 ms delay. There is no packet loss for all three types of transmissions.

On the other hand, UMTS-WiMAX conference experience a lower packet delay variation (10~15 µs) compared to the Ethernet-WiMAX (20~40 µs) and the WiFi-WiMAX (40~60 µs) transmissions. All participants experience an equal end-to-end packet delay to the conference session with the urban user in the Ethernet cluster. There was no packet loss for all type of transmissions.

In the second scenario, likewise video transmissions not all participants are able to receive voice data successfully. In case of UMTS-Ethernet pair communication, only two out of ten users are able to receive data. All participants under Ethernet-Ethernet and WiFi-Ethernet conference are able to receive data. However, the quality does not meet the expected level. Similarly, all users under the Ethernet and the WiFi cluster are able to receive transmission from the urban user in the WiMAX cluster. However, some of the participants experience poor quality. Only two out of ten users from the UMTS cluster are able to receive data successfully.

After decreasing the number of participants, Ethernet-Ethernet and WiFi-Ethernet pair voice transmissions experience insignificant packet losses. UMTS-Ethernet conference experience more packet loss in comparison with the former two types of conferences. The conferences with the urban user in the Ethernet cluster show a higher degree of packet loss than the conferences with the user in the WiMAX cluster. Figure 5 shows the number of successful received packets for participants from the WiFi cluster. It is clearly visible from the figure that the WiFi-WiMAX conferences show less packet loss. Figure 6 shows a comparison between the number of successful packets received for UMTS-Ethernet and UMTS-WiMAX conferences. UMTS-WiMAX conference show less packet loss compared to the UMTS-Ethernet conference.

The values of end-to-end delay do not vary much in presence of large and few numbers of simultaneous participants. However, in terms of packet loss, voice transmissions from different pair conferences show different behaviors. When the simulation is carried out with twenty different simultaneous users, the conferences, which take place with the urban user in the Ethernet cluster, experience the highest amount of packet loss.

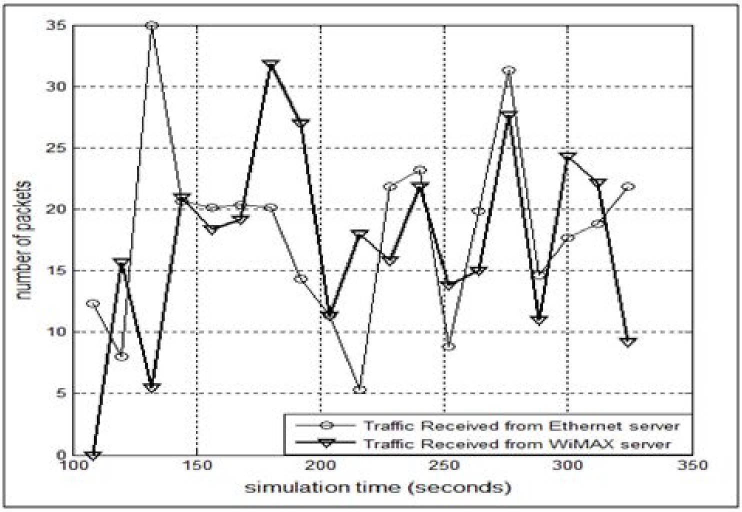

Fig. 5. Successful received packets for WiFi clients in voice transmissions

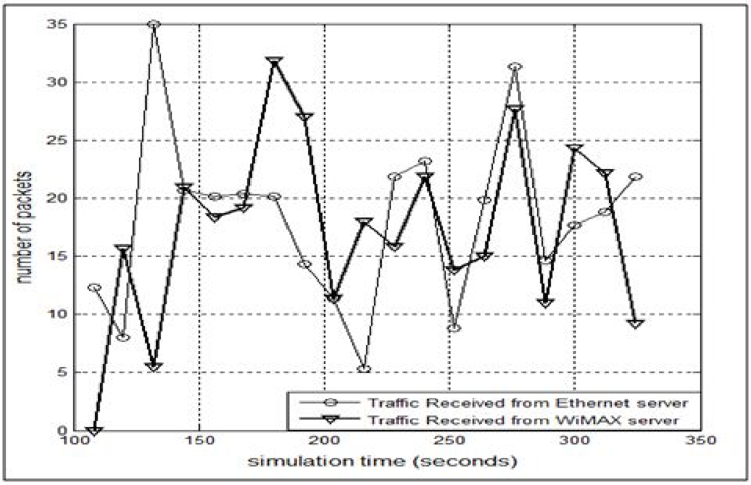

Fig. 6. Successful received packets for WiFi clients in voice transmissions

On the other hand, the conference which takes place between the WiFi and the WiMAX cluster, regardless of the number of simultaneous users, voice transmissions experience no packet loss. However, conference between the Ethernet and the WiMAX cluster and the UMTS and the WiMAX cluster experience some degree of packet loss.

To summarize, with ten simultaneous participants in each VC session the voice transmission experience better performance. Conference with the user in the WiMAX cluster exhibits better transmission quality. Voice transmissions in the conference with the user in the Ethernet cluster experience some amount of packet loss. Participants in the UMTS cluster experience better performance in case of voice transmissions compared to video transmissions. Only voice transmissions met acceptable performance level after increasing the number of simultaneous user in the UMTS cluster.

5 Conclusions

In this paper, we have proposed and reported on studies of heterogeneous network-based architecture for rural areas. Our analyses, based on simulations using OPNET Modeler, have focused on interactive education applications. Three main types of network technologies are considered for rural areas. These include, WiFi, 3G and particularly UMTS, and Ethernet. For urban areas WiMAX and Ethernet are the main technologies studied for use in urban area. Videoconferencing sessions, involving different communication technologies and variant number of participants, are initiated between rural and urban areas. The performance of the system, in terms of capacity, end-to-end packet delay, delay variation, and packet loss are then analyzed. The simulation results show that, the architecture can support up to ten simultaneous participants in each session. The results also show that the conference sessions exhibit higher levels of performance when the combination of WiMAX in urban areas and WiFi in rural areas are utilized. In our future works, we intend to evaluate the performance of this architecture for other symmetric and non-symmetric real-time and non real-time applications. We also intend to investigate how different admission control and adaptive videoconferencing algorithms can be used to improve the overall system performance.

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