Quality-controlled Prioritized Adaptive Multimedia Streaming for WiMAX-based Cellular Networks

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Abstract—**Live multimedia streaming is one of the greatest promise of the wireless network operator. In recent years, there has been an upsurge of interest in the feedback-oriented multimedia streaming in the wireless domain, in both industry and academia. However, the lack of an acceptable and guaranteed quality of service (QoS) in the wireless domain results in the media packets experiencing dynamic variations in bandwidth, delays and loss rate as the packets traverse from the sender to the receiver. In this work, a WiMAX-based two-hop cellular network is considered for multimedia transmission across different hand-held wireless devices.**

The novelty of this paper is in the design of a prioritized model, wherein, the different clients are served under different categories of perceived quality (*satisfactory, good and excellent*), depending on the end-user's selection choice. It has been observed through extensive simulation of different kinds of video streams (*low, medium* and *high action*) that such a prioritization not only results in a higher average perceived quality of the network but also provides a higher perceived quality to most of the the end users, as compared to the case when there is no prioritization.

Keywords: multimedia streaming, quality oriented adaptive scheme (QOAS), proxy server, perceived quality, two-hop cellular

1 Introduction

Over the last decade, there has been a tremendous growth in the telecommunication world, in providing voice and data services. The next demand is for live multimedia streaming and video broadcasting over a hand-held wireless device. However, triple play services (voice, data and video) are yet to be fully implemented and deployed in the market. There are significant technological bottlenecks that hinders its deployment in the wireless world. There are many challenges exist in the design of video streaming systems. Firstly, the time delay is usually very high, thereby causing great difficulty in real-time video broadcasting. Secondly, the power required at the hand-held device for multimedia transmission is very high. In case of video broadcasting, the battery does not last for more than few hours. Thirdly, the wireless channel changes rapidly, when the distance between the source and the destination node is high. This would in-turn require huge computations in order to provide efficient multimedia delivery, which again causes reduction in the battery power. Hence, alternate techniques have to be adapted in order to have high quality multimedia transmissions in the wireless network.

The integration of multihop design into the conventional hierarchical wireless networks is one of the most promising architectural upgrade to meet the the next generation demand of multimedia transmission in cellular networks. In such a design, the base station (BS) (associated with a web server) communicates with the end-users in multiple hops, through the intermediate relays. The BS communicates with the far-off wireless terminals through these relay nodes. This results in a shorter transmission distance, and thereby less transmit power for the transmitter, which in-turn results in less interference and importantly, higher data rates. There has been significant amount of research work done in the recent years on multihop cellular networks and the type of relaying strategies [1]. It has been proved that multihop transmission increases the capacity of a wireless network [2, 3]. However, optimum resource allocation in multihop cellular network is an NP-hard problem [4]. Hence, the researchers have focused mostly on two-hop wireless networks [5]. Recently, a cluster-based architecture has been proposed in [6, 7] for two-hop cellular networks, that not only increases the frequency reuse in the cellular network, but also provides an increase in the data rate without an increase in the power requirement, thereby enabling high quality multimedia transmission, without losing the battery power significantly.

In a wireless environment, the unpredictability and the

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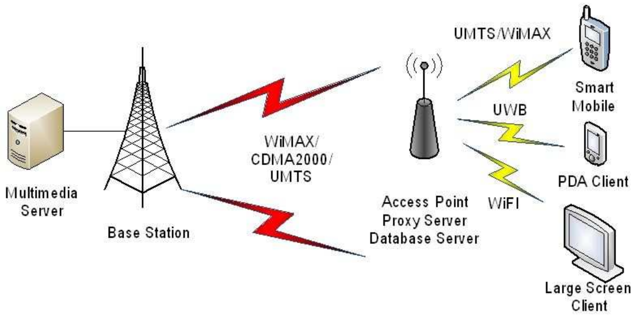

Figure 1: A two-hop cellular network with the relay node acting as both proxy server and database server

constantly varying nature of the wireless channel necessitates the implementation of the feedback-based quality oriented adaptive scheme (QOAS) [8]. The adaptive multimedia streaming solution maximizes the end-user perceived quality in highly variable and increasingly loaded network delivery conditions. However, QOAS does not assign any priority to any specific users. However, given the diverse nature of today's wireless devices, various end-users/clients need to have different priorities based on its device characteristics, i.e., the screen size and resolution, whether they support full color or reduced grayscale, the amount of available local memory and the CPU power (hardware variations), application level data encodings that the client can handle given the processing and display capabilities of the end service (software solutions). In addition, the priorities need to be assigned based on the client's requirement of the *perceived quality* and his/her ability to pay for that particular video program. Hence, in this paper, a novel prioritization scheme is proposed for efficient multimedia transmission. This is combined with QOAS to form the *quality-controlled prioritized adaptive multimedia scheme* - QPAMS.

The goal of developing QPAMS is to have a resource-based adaptive scheme for multimedia streaming which would fairly distribute the user quality of experience (QoE) among different devices based on their characteristics and subjective priorities associated by their users.

The paper is organized as follows: Section 2 describes the QPAMS in detail, in conjunction with the feedback-based QOAS and the proposed prioritization mechanism. The simulation model and the results are described in Section 4, whereas the conclusions and the possible directions for future work are provided in Section 5.

2 QPAMS

A two-hop cellular wireless network is established, as shown in Fig. 1. The BS acts as the multimedia source and transmits its signal/information to the proxy server (PS). The multimedia information is stored in the PS. It is assumed that there is enough memory space in the PS and that the PS also acts as a database server. Each PS serves multiple clients. A quality oriented adaptive scheme (QOAS) is set-up between the PS and each of the clients. Hence, the adaptation strategy is different for each end-user, and is decided by the PS. The significant advantage of having a PS is that it could also act as a proxy client (PC) to the main multimedia server (base station). In fact, applying a feedback-based QOAS scheme between both BS and proxy node (PC/PS) and between the proxy node and the end-user would increase the overall QoS of the end-to-end link. However, that would increase the overall complexity an the of the system, in addition to causing an increase in the required time. Also, the proxy node has to be intelligent in order to serve as both PC and PS. Hence, a PC/PS combination for the proxy node is left for future work and not considered in this paper.

2.1 Adaptive Multimedia Streaming

In order to support live multimedia streaming and video broadcasting in wireless network with guaranteed quality of service (QoS), a client-server based feedback approach is required, wherein, the client monitors the transmission and user QoE-related parameters, and sends them as feedback to the server which in turn adjusts the video transmission rate. An advantage of deploying the client-server topology is that the availability of servers ensures that a client can easily locate the services, often being able to retrieve the content quickly when the system is not overloaded. The state-of-the-art methodology for achieving the same is the quality oriented adaptation scheme (QOAS). In the QOAS approach, the client monitors the transmission and user quality of experience (QoE) related parameters, and sends them as feedback to the server which in turn adjusts the video transmission rate. This is based on the fact that random losses have a greater impact on the perceived quality than a controlled reduction in quality.

QOAS adjusts the content as well as the transmission rate, increasing or decreasing the quantity of streamed video data by dynamically adjusting its quality [9]. This is done according to feedback information received from the client. The QOAS-based system architecture includes multiple instances of QOAS adaptive client and server applications that bi-directionally exchange video data and control packets through the delivery network. During transmission the server dynamically varies its state according to the reported end-user stream quality. For example, when the client reports a decrease in end-user quality, the server switches to a lower quality state, which reduces the quantity of data sent. In improved viewing conditions, the server gradually increases the quality of the delivered stream using the Quality of Delivery Grading Scheme (QoDGS). QoDGS regularly computes the quality of delivery scores, which are sent as feedback to the server. The QoDGS takes into account end-user qual-

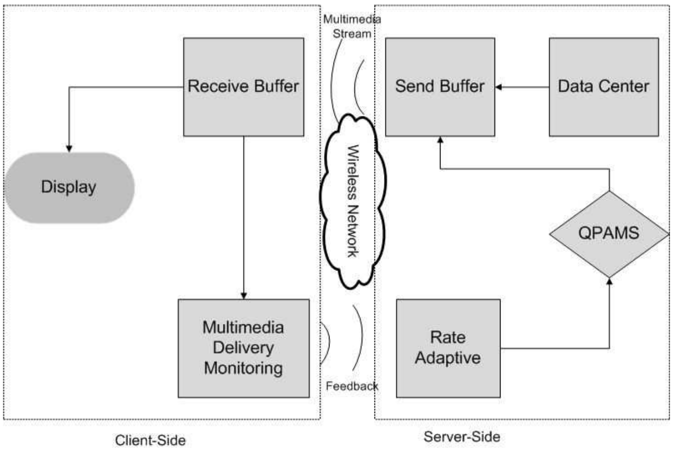

Figure 2: System Design for client-server based QPAMS transmission technique

ity as measured by the moving pictures quality metric Q, which maps the joint impact of bitrate and data loss on encoded video streams quality onto the ITU-T R P.910 five-point grading scale [10].

3 Prioritized Multimedia Transmission

In a prioritized multimedia transmission scenario, the aim is to have different priorities with regard to the perceived quality of the received video signal for different end-users under the same PS. There are M categories onto which a received video stream could be divided into, depending on the user's perceived quality. For example, in case of $M = 3$, the video stream could be classified into three categories as below:

1. **Satisfactory, Q_1:** Perceived quality greater than 2.
2. **Good, Q_2:** Perceived quality greater than 3.
3. **Excellent, Q_3:** Perceived quality greater than 4.

The client priorities are supported by the biasing done in resource allocation/bandwidth. For a given video type of video stream, a user demanding higher perceived quality requires higher amount of resources as compared to a user seeking lower perceived quality. The main idea of QPAMS is to categorize the users, depending on the device characteristics and the ability of the client to pay for the video stream. Such a prioritized video transmission technique also enables the network operator to bring in more revenue by providing an adaptive service to the end-users. It is based on a client-server based feedback mechanism which enables the adaptation to be performed. Fig. 2 illustrates the system architecture of QPAMS. A key component at the client side is the *multimedia delivery monitoring* module that monitors the delivery in terms of multimedia quality according to client priority. The key component at the server-side is the QPAMS module which performs the adaptation and prioritization. The QPAMS at the server then decides the extent of adaptation, and also the category of prioritization for each user, depending on his/her demand, and the availability of the bandwidth resource.

3.1 Bandwidth Allocation

In a non-prioritized transmission technique, all the clients requesting the server simultaneously are treated equally. If B is the total bandwidth and N is the number of simultaneously communicating clients under the PS, then the bandwidth allotted to each client in case of equal treatment would be B/N. However, in case of a prioritized transmission scheme, clients with different priorities would receive different bandwidths. If r is the priority factor for a client, then the bandwidth for the communicating client is $w = \frac{B}{N} \times r$. In case a client has higher priority, then the average bandwidth resource factor given to a user is, $r > 1$, and in case, a client has lower priority then the average bandwidth resource factor given to a user is, $r < 1$. It should be noted that the maximum average value of the factor, r over N users is *one*, implying that the maximum available bandwidth, B, is utilized by the system.

The end-user quality is computed using the multimedia *perceived quality* metric proposed in [11] and expressed using the ITU-T R P.910 five-point scale for grading subjective perceptual quality [10]. If the total users are classified into M categories according to the prioritization schedule, then the perceived quality of the i^{th} category would be given by:

$$Q_i = Q_0 + \chi_Q \times \left(\frac{R_i}{\chi_R}\right)^{-\frac{1}{\xi_R}} + \chi_L \times R_i \times \text{PLR} \tag{1}$$

It can be seen that Q of a particular category depends on both the packet loss rate (PLR) of the channel and the mean bit rate, R. The bit rate of a user in the category i would be given by:

$$\begin{aligned} R_i &= \alpha \times w_i \times n \qquad (2) \\ &= \alpha \times \frac{B}{N} \times r_i \times n \qquad (3) \end{aligned}$$

where n is the number of bits/symbol and it depends on the modulation technique; and α is the proportionality constant having value 1.8. In the prioritized technique, the bandwidth ratio allotted to each category of users not only determines the perceived quality of users in each category, but also plays an important role in determining the average perceived quality of the network. If Q_1, Q_2, ..., Q_M are the average perceived quality of the users in each of the M categories, and U_1, U_2 ..., U_M are the number of users in each category, then the average perceived quality of the network is given by:

$$Q_{\text{avg}} = \frac{1}{U_i M} \sum_{i=1}^{M} U_i \times Q_i = \sum_{i=1}^{M} \sum_{j=1}^{U_i} Q_{i,j} \qquad (4)$$

where $Q_{i,j}$ is the perceived quality of the j^{rmth} user in the i^{th} category. It should be noted that $\sum_{i=1}^{M} \sum_{j=1}^{U_i} = N$, the total number of clients served by the proxy server. All the clients belonging to the same category is allotted the same bandwidth ratio. The PLR, the number of bits/symbol and the bandwidth of the system are usually fixed for a system. Hence, it can be seen from (1), (3) and (4) that for a given number of communicating clients N (served by one PS), the average perceived quality of the network, Q_{avg}, is a complex nonlinear function of the number of users in each category, U_i, and the bandwidth ratio assigned to each category, r_i, i.e.,

$$Q_{\text{avg}} = f(U_1, r_1, U_2, r_2, ...U_M, r_M) \qquad (5)$$

In order to assess the performance of the prioritized technique in QPAMS, the number of users served by the proxy server, N, is kept constant and the number of users in each category is varied dynamically over all possible combinations. The average perceived quality of each category and of the entire network is determined through the simulator.

4 Modeling and Simulations

4.1 Simulation Setup

The hierarchical multimedia network is established with a single server, a single proxy-server and N clients belonging to a single proxy-server. The video streams are categorized into 3 different sections, based on their perceived quality, i.e., $M = 3$. The topology proposed assumes a bandwidth of 5 MHz and a constant delay of 2 μsec. In each of the envisaged scenarios 95-99% of the total available bandwidth is used for video and multimedia communication and the remaining 1-5% is reserved for feedback purpose. A constant PLR of 10^{-7} is assumed throughout the analysis. Similarly, a constant transmission delay of 10ns is assumed between the PS and the end-uusers. The entire network is simulated using NS2.31.

An important factor that R depends on is the number of bits/symbol, n. In case of QPSK modulation technique, $n = 2$, whereas in case of 8-PSK modulation technique, $n = 3$. An higher modulation technique requires higher SINR (signal to interference noise ratio) at the receiver of the communicating link, but at the same time would result in higher Q. In this simulator, the video streams are assumed to be modulated with QPSK modulation technique, i.e., $n = 2$. In addition, there are different kinds of video and multimedia programs in reality, depending on the temporal complexity of the video program. Temporal complexity implies the number of changes in the pixels per video frame. Each multimedia program has different requirements, in terms of the action sequence and the rapid movement of pictures. Hence, in terms of temporal complexity, the video programs are usually classified into $M = 3$ sections:

1. **Low Action:** This is the 1^{st} section in the classification of temporal complexity and has no/little movement in the background. There is very little difference between the subsequent frames and the bit rate requirement is the least for this category. Hence, it is sufficient to have a perceived quality greater than 2 for watching such programs with decent quality.
2. **Medium Action:** The 2^{nd} category is the general video programs/SOPs/ drama scenes where the number of scene changes per second is higher than the *low action* category. Hence, a higher bit rate and a Q greater than 3 is required for viewing good quality videos.
3. **High Action:** This is the 3^{rd} in the temporal complexity classification of video frames, and it comprises of action/ blockbuster movie or a live soccer/sports match. These video sequences have lots of actions, and hence, demands a very high bit rate and a Q greater than 4 in order to have good quality.

The constants used for the calculation of Q have been taken from [11], viz., $Q_0 = 5.225, \chi_Q = -0.045, \chi_R = 124.762, \xi_R = 1.116$ and $\chi_L = -33.9$ (for the case of high-action video transmission). For low-action video frames like news channel, the values for Q_0 and χ_Q would be given by, $Q_0 = 5.062, \chi_Q = -0.025$, with other constants being the same. For medium-action video transmission, constants have been calculated based on the given slope of the line just as those used in high and low action transmission have been calculated , viz., $Q_0 = 5.115, \chi_Q = -0.035$, with the other constants again being the same.

4.2 Simulation Scenarios and Results

The simulation scenario considers a single PS serving 6 different clients ($N = 6$). The multimedia stream is an MPEG4 video with all three possible combinations of temporal complexity in the video broadcasting, i.e., low, medium and high action. Table I shows the results for three different kinds of video streams, when the bandwidth ratio for each category of users (*satisfactory, good* and *excellent*) is set to 0.6, 1.0 and 1.3. It can be observed that when there are equal number of users ($U_1 = U_2 = U_3 = 2$) in each category, the obtained perceived quality for the users selecting *good* and *excellent* viewing is higher than what would be obtained when there is no adaptation among the users and all the users having the same perceived quality. For example, it can be observed from the 1st section in Table I that when a *low action* video stream is selected, the perceived quality when there are two users in each category is: 2.712, 3.392 and 4.421, whereas the Q in case of all users being in same category is 3.257. A similar result pattern is observed for *medium action* and *high action* video streams, as can be observed from Table I. In addition, the results in Table I indicate that the average perceived quality in case of *high action* video stream is less than that of the *medium action* stream which in-turn is less than the average perceived quality of a *low action* video stream.

In an important observation obtained, the average perceived quality of the entire network is higher when there is a prioritization among the different users, as compared to the case when all the users have the same priority. This can also be observed in Fig. 3, for a *low action* video sequence. In case of unequal number of users (1:3:2, 1:2:3 and 3:2:1), the average perceived quality is higher than that obtained when there are equal users (2:2:2) in each category. Also, as can be observed in Table I, the obtained average perceived quality is notably higher as compared when all users are in same category. This is a very significant observation and it implies that prioritization among users not only provides an increase in the perceived quality for certain section of users in the network, but also increases the average perceived quality of the entire network. Also, as can be seen from Table I, this observation is consistent among all three kinds of MPEG4 video streams, i.e., *low, medium* and *high action*.

In order to assess the performance of the prioritization scheme, the number of users served by the proxy server was kept constant at 6. The bandwidth ratio for three categories of users were changed to 0.7, 1.05 and 1.2, and the network was simulated again. The results obtained in Table II show the same pattern as observed in Table I. A significant observation was obtained by comparing the results in Table I and Table II. By only changing the bandwidth ratio of each category whilst keeping the number of users same, the average perceived quality of each category and of the entire network varied significantly. For example, in case of having (1,2,3) users in the three categories of *satisfactory, good* and *excellent*, the average perceived quality of the network for *low action* video stream is 4.441 for a ratio of 0.6, 1.0 and 1.3. This value was 3.788 for a ratio of 0.7, 1.05 and 1.2 among the three categories, for the same number of users. A similar variation in the results was observed for both *medium* and *high action* video streams.

5 Conclusions

A novel prioritization mechanism is introduced in this paper for adaptive multimedia transmission in WiMAX-based two-hop cellular networks. The prioritization of users not only enables better perceived quality for cer-

Table 1: Variation of the perceived quality with the number of users for three categories (*satisfactory, good* and *excellent*) for *low action, medium action* and *high action* video sequence - 0.6, 1.0 and 1.3 are the bandwidth ratio for the three action sequences

U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	2.712	3.392	4.421	3.408
1	3	2	3.619	4.571	4.687	4.451
1	2	3	3.619	4.463	4.699	4.441
3	2	1	4.387	4.612	4.699	4.514
0	0	6	NA	NA	3.257	3.257
0	6	0	NA	3.257	NA	3.257
6	0	0	3.257	NA	NA	3.257
U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	3.554	4.428	4.651	4.211
1	3	2	3.094	4.428	4.590	4.259
1	2	3	3.094	4.428	4.607	4.281
3	2	1	4.169	4.484	4.607	4.347
0	0	6	NA	NA	4.428	4.128
0	6	0	NA	4.428	NA	4.128
6	0	0	4.428	NA	NA	4.128
U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	3.217	4.342	4.629	4.063
1	3	2	2.627	4.342	4.550	4.125
1	2	3	2.627	4.146	4.572	4.104
3	2	1	4.009	4.414	4.572	4.238
0	0	6	NA	NA	4.342	4.042
0	6	0	NA	4.042	NA	4.042
6	0	0	4.042	NA	NA	4.042

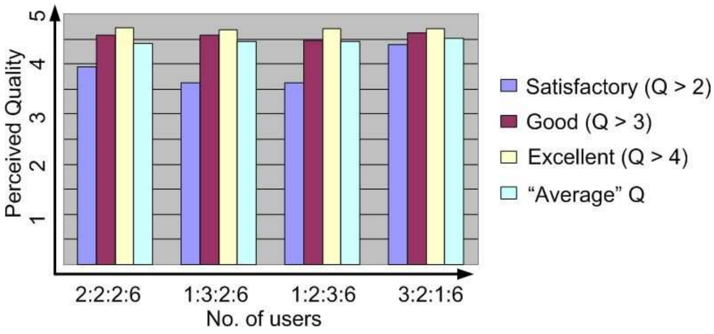

Figure 3: Variation in perceived quality for users in different categories

Table 2: Variation of the perceived quality with the number of users for three categories (*satisfactory, good* and *excellent*) for *low action, medium action* and *high action* video sequence - 0.7, 1.05 and 1.2 are the bandwidth ratio for the three action sequences

U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	2.527	3.947	4.309	3.594
1	3	2	2.986	3.947	4.078	3.831
1	2	3	2.986	3.700	4.115	3.788
3	2	1	3.527	4.038	4.237	3.816
0	0	6	NA	NA	3.547	3.547
0	6	0	NA	3.547	NA	3.547
6	0	0	3.547	NA	NA	3.547
U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	2.209	3.554	4.229	3.331
1	3	2	2.209	3.553	4.171	3.534
1	2	3	2.207	3.208	4.116	3.495
3	2	1	2.966	3.681	4.214	3.412
0	0	6	NA	NA	3.325	3.325
0	6	0	NA	3.325	NA	3.325
6	0	0	3.325	NA	NA	3.325
U_1	U_2	U_3	Q_1	Q_2	Q_3	Q_{avg}
2	2	2	2.452	3.217	4.098	3.255
1	3	2	2.489	3.217	4.104	3.391
1	2	3	2.499	3.273	4.052	3.533
3	2	1	2.662	3.382	4.037	3.131
0	0	6	NA	NA	3.114	3.114
0	6	0	NA	3.114	NA	3.114
6	0	0	3.114	NA	NA	3.114

tain categories of users, but also improves the overall perceived quality of the network. For a given number of users in the network, the amount of improvement depends on the assignment of bandwidth resource to each category of users. With this regard, different kind of resource allotment results in different amount of increase/decrease in the perceived quality. An important task for future research work is to analyze the prioritization aspect in QPAMS and find out the optimal values for the bandwidth allotment ratios that would maximize the perceived quality of each category and of the entire network.

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