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CASHeW: Cluster-based Adaptive Scheme for Multimedia Delivery in Heterogeneous Wireless Networks

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Abstract Multimedia streaming over heterogeneous wireless networks has attracted significant interest in recent years from both telecom network operators and end users. However, the heterogeneity of the wireless network makes it very difficult to synchronize real-time multimedia streaming to different types of end-user devices across different wireless networks. In addition, with different delay and packet loss across different networks, multimedia delivery over the heterogeneous wireless networks cannot provide good quality streaming video. This paper proposes CASHeW—a novel cluster-based design with an in-built feedback-based adaptive mechanism that results in a higher video perceived quality in two-hop heterogeneous wireless network environments. CASHeW employs a proxy-client-server mechanism between the base station (BS) and the end-user; and importantly uses a quality-oriented adaptive scheme for efficient multimedia delivery. Simulation-based tests indicate that the performance of CASHeW not only outperforms transport layer adaptive delivery protocols like the TCP-Friendly Rate Control Protocol (TFRCP) and Loss Delay Adaptation (LDA+), but also is better than that of medium access control (MAC) layer protocols such as the Receiver Based Auto Rate (RBAR) and Enhanced Distributed Channel Access (EDCA) in terms of average perceived quality, average bit rate and loss rate.

Keywords Adaptive scheme · Base station · Cluster-based design · Gateway · Mobile station · Multimedia · Two-hop

1 Introduction

The wireless industry has evolved rapidly over the last decade or so. The wireless technology has progressed from carrying simple voice services and basic text-based messages to

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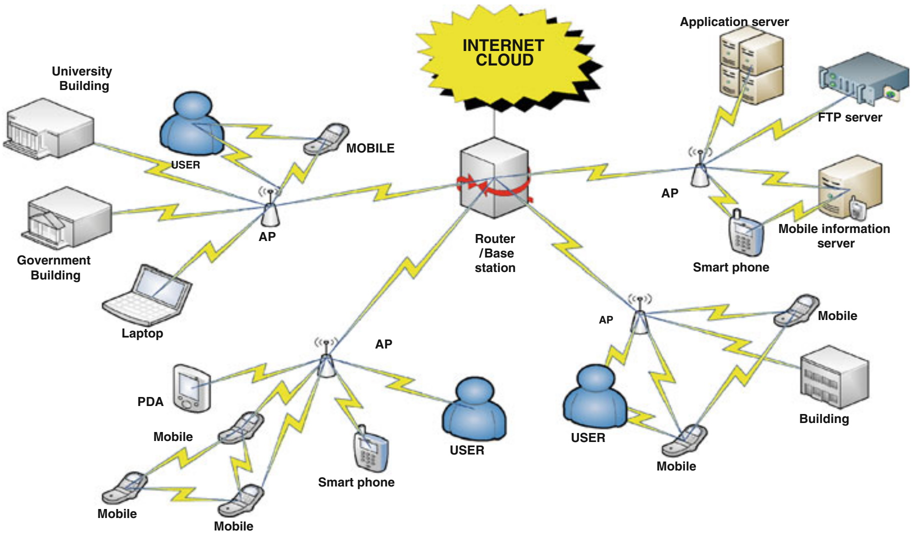


Fig. 1 General multihop cellular architecture

more complex email and web traffic, and then to supporting multimedia applications like voice over IP, video conferencing and video-on-demand. The user today not only wants to stay connected at any place and at any point of time, but also wants high quality information and entertainment programs at a very affordable cost. The next generation wireless networks strive to achieve these requirements and in the process, have brought many significant changes in data networking including an all-IP approach [1]. Therefore, in order to support video transmission over a wide coverage area, a fundamental change in the wireless architecture is required.

A ubiquitous wireless multimedia transmission calls for communication across a heterogeneous wireless network which in-turn demands multihop communication between the source and the destination node. The multimedia transmission between different wireless devices would be established over a multihop heterogeneous wireless network (Wi-Fi, WLAN, WiMAX, WAN, MAN, etc) using a novel proxy-client-server model. However, multihop design causes an increase in the overhead signals, and significantly, results in an increase in time delay in the network [2]. In addition, real-time delivery of information is extremely time-sensitive and does not allow delay and jitter in the incoming signals. Given these technological bottlenecks, in spite of being extensively researched over the last decade, peer-to-peer distributed multihop transmission for multimedia delivery would probably take few more years to come up as a practical solution [3].

A heterogeneous hierarchical multihop design with a single central entity and several smaller devices that would serve as intermediate relays is shown in Fig. 1. The relays reduce the transmission distance between a Tx–Rx pair which in turn reduces the power requirement and at the same time, increases the achievable maximum data rate of a communicating link [4].

There have been a couple of landmark papers on multihop wireless network over the last decade for high data rate transmission [5,6]. Kumar [5,7] proved that the data rate and thereby the system capacity increases as $O\left(n^2\right)$, with an increase in the number of nodes n in the network. In a landmark paper, Grossglauser and Tse [6] proved that mobility of a node in a network can actually cause an increase in the data rate in a multihop wireless network. In another significant result, it is shown that the data rate can be increased significantly along with a significant reduction in the outage when the traffic is diverted from *hot* (highly loaded) cells to *cool* (lightly loaded) cells in a cellular network [8]. However, these benefits are obtained at the expense of an increase in the complexity of solution management, required signaling and most importantly in the power consumption at the relay nodes. In addition, optimum resource allocation in multihop cellular networks is an NP-hard problem [9]. Also, the deployment costs increase with an increase in the number of hops. Hence, a great amount of focus for high data rate solutions in recent years has been on two-hop wireless networks [10–12].

An important aspect during multimedia transmission over wireless networks is the continuous variation in the end-user perceived quality due to the continually changing conditions in the wireless channel. Additionally, there are different kinds of wireless devices (laptops, PDAs, smart phones, etc.) which have different screen sizes and device characteristics and require personalized treatment. In order to ensure that all users receive good video quality levels at their various devices, the multimedia content delivery needs to be adapted dynamically to current wireless network conditions.

This paper proposes CASHeW—a novel cluster-based feedback-oriented adaptive scheme for quality-oriented multimedia streaming across two-hop heterogeneous wireless networks. CASHeW employs a two-stage adaptation mechanism deployed in a client-proxy-server manner, which extends the Quality-Oriented Adaptive Scheme (QOAS) proposed for deployment in single hop networks [13]. It involves client multimedia delivery quality monitoring and feedback sending, proxy-side preliminary adaptation decision making and relaying of information to the server and server-based aggregation of data, final adaptation decision making and delivery process adjustment.

The description of CASHeW includes the two-hop network-based architecture and the feedback-oriented adaptive mechanism. The performance of CASHeW is analyzed in terms of the average end-user perceived quality, average throughput and loss rate; and is compared with other existing protocols in both single-hop homogeneous and two-hop heterogeneous network environments.

The organization of this paper is as follows: Sect. 2 contains related works, Sect. 3 describes CASHeW in detail and Sect. 4 presents testing and performance analysis. Finally, Sect. 5 concludes the paper.

2 Related Works

The demand for multimedia streaming in wireless communications has experienced significant growth in recent years. Various avenues have been researched in order to increase user perceived quality and several approaches have been proposed. TCP-Friendly Rate Control Protocol (TFRCP) is a unicast transport layer protocol designed for multimedia streaming which provides nearly the same throughput as that of TCP over wired networks [14]. TFRCP enables delivery rate adaptation to network conditions making use of regularly updated delivery-related information such as round trip time and packet loss [15]. The main disadvantage of TFRCP is that it considers loss to be caused by congestion only. Consequently, TFRCP flow over wireless link experiences performance degradation as it cannot distinguish wireless loss over congestion loss. Similar to TFRCP, the Enhanced Loss Delay Adaptation algorithm (LDA+) also regulates the transmission behavior of multimedia transmitters in accordance with network congestion [16]. LDA+ uses the information carried by the

Real-Time Control Protocol (RTCP) to calculate loss and delay and uses it to adjust transmission rates. As LDA+ also adapts the delivery based on un-differentiated loss, it has the same limitations as that of TFRCP. Hence, both LDA+ and TFRCP do not provide good adjustments in a dynamic wireless environment.

A more recent sender-based solution is the Rate Adaptation Protocol (RAP) [17], an end-to-end congestion control mechanism which employs an additive-increase, multiplicative-decrease (AIMD) algorithm. It is well suited for unicast delivery of real-time streams, but was never properly tested in a wireless environment to see how it would cope with increased and highly variable loss.

The Receiver-Based Auto Rate (RBAR), on the other hand, is a MAC layer protocol and was designed specifically for wireless communication, making use of the Request-To-Send (RTS)/Clear-To-Send (CTS) mechanism [18]. The main feature of RBAR is that both channel quality estimation and rate selection mechanism are on the receiver side. This allows the channel quality estimation to access directly all the information available at the receiver (number of multipath components, symbol error rate, received signal strength, etc.) and use it for more accurate rate selection. In addition, since the rate selection is done during the RTS/CTS exchange, the channel quality estimates are performed near to the actual transmission time of the data packet unlike in the normal sender-based approaches when there are inherent delays which may affect the accuracy of the estimation. In addition, instead of carrying the duration of the reservation, the packets in RBAR carry the modulation rate and the size of the data packet. This modification serves the dual purpose of providing a mechanism by which the receiver can communicate the chosen rate to the sender, while still providing neighboring nodes with sufficient information to calculate the duration of the requested reservation time period.

The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) can differentiate high priority traffic such as real-time voice or video from low priority traffic at the MAC layer [19]. EDCA controls the access to the wireless channel based on channel access functions (CAFs). Each CAF executes an independent back-off process to determine the transmission time of its frames. Another receiver-based mechanism is the Receiver-driven Layered Multicast (RLM) [20]. This application-layer protocol uses a cumulative layering, where data (audio, image, video) is divided in different layers, where each layer provides refinement information to the previous layers. Each layer is sent in a different multicast group. The sources take no active role in the algorithm, as the receivers implement all the logic of the protocol, adapting to the network conditions, i.e., each receiver adapts to congestion by joining and leaving multicast groups and consequently varying the amount of information which reaches them. Finally, there is no explicit signaling between the receivers and routers or between the receivers and source. Even though this is good when multicast is enabled, in a wireless environment there are still difficulties in implementing it.

It should be noted that the algorithms described above (sender-driven and receiver-driven algorithms) do not directly consider user perceived video quality of streamed multimedia content. In addition, the above-described algorithms do not provide any optimal congestion control in wireless environments and therefore, they do not guarantee the necessary quality of streamed multimedia content. Hence, it is imperative to develop new adaptive schemes or improving the algorithms previously described. In addition, these protocols (TFRCP, LDA+, RBAR and EDCA) do not show a smooth transition in the perceived quality, required for adaptive multimedia transmission [21]. This explains why these protocols do not show good adaptation results for multimedia on wireless communication.

The Quality Oriented Adaptive Scheme (QOAS) [22] is an application-layer adaptive solution for multimedia delivery which actively involves user perceived quality estimation in the feedback-based multimedia adjustment process. Testing results have shown how QOAS provides significant improvements in end-user perceived quality in both wired and especially wireless environments.

It is important to note that, all the above-mentioned algorithms were designed for single-hop solutions and they may not be suitable for using in multihop deliveries. In particular it is worth noting that there are no specific transmission protocols for multihop wireless networks, even for a two-hop scenario. Hence, there is a need to develop solutions which would cater to the next generation networks' demand for both single-hop and multihop delivery.

3 CASHeW Architecture—Cluster-based Design and Efficient Multimedia Delivery Over Heterogeneous Wireless Network

3.1 Cluster-based Multihop Design

CASHeW is deployed on a cluster-based architecture designed for multi-hop heterogeneous wireless networks. In order to understand the principle of and the mechanism behind CASHeW, the heterogeneous network architecture is initially restricted to two-hop, leaving the design of CASHeW for solutions with higher number of hops to future work.

Figure 2 shows a schematic of a hierarchical cluster-based two-hop architecture where there are six clusters in a circular coverage area, which is henceforth denoted as a cell. In reality, the outer circular area could be a cell in a cellular network or the coverage area of a WLAN environment. Each cell is initially divided into two layers: an inner layer and the outer layer. The wireless nodes in the inner-layer communicate directly with the Base Station (BS) whereas the wireless terminals in the outer-layer are grouped into several clusters and communication is performed via an Access Point (AP). In the two-hop scenario considered by CASHeW, the link between the BS and the AP could be enabled by GPRS, 3G, WiMAX or IEEE 802.11 technologies, whereas the link between the AP and the end-user devices or Mobile Stations (MS) would be usually an IEEE 802.11 or a UWB/Zigbee network. In general, the heterogeneity in the multihop network could be realized by having different wireless technologies across the different communicating links. Importantly, in this paper, it is considered that the APs (relays/proxy-server) would be able to seamlessly switch between the two heterogeneous wireless technologies.

The CASHeW adaptive scheme in this cluster-based design has two server-client instances (one between the BS and the AP and the other between the AP and the end-users'). For each of the clusters, the AP acts as both client (for the server) and as server (for the end-users) and hence it enables bridging between the two components of the heterogeneous wireless network environment, establishing a proxy-client-server architecture and performing two-hop adaptive streaming.

One of the main limitations in the implementation of such a multihop design for wireless network is the interference arising from simultaneous communication of multiple communicating pairs [23]. A *Protocol Model* is considered for interference avoidance in this two-hop design, as is done in the landmark paper of Gupta and Kumar [5]. As per this model, if there is any transmitter (Tx)—receiver (Rx) pair of distance, d_c, communicating with each other, then an exclusion region of *twice* the transmission distance, i.e., $2d_c$, is defined around the Rx node. All transmitters that are outside the exclusion region of the desired receiver can transmit simultaneously along with the Tx, provided all the transmitters are outside the exclusion region of all other simultaneously communicating receivers.

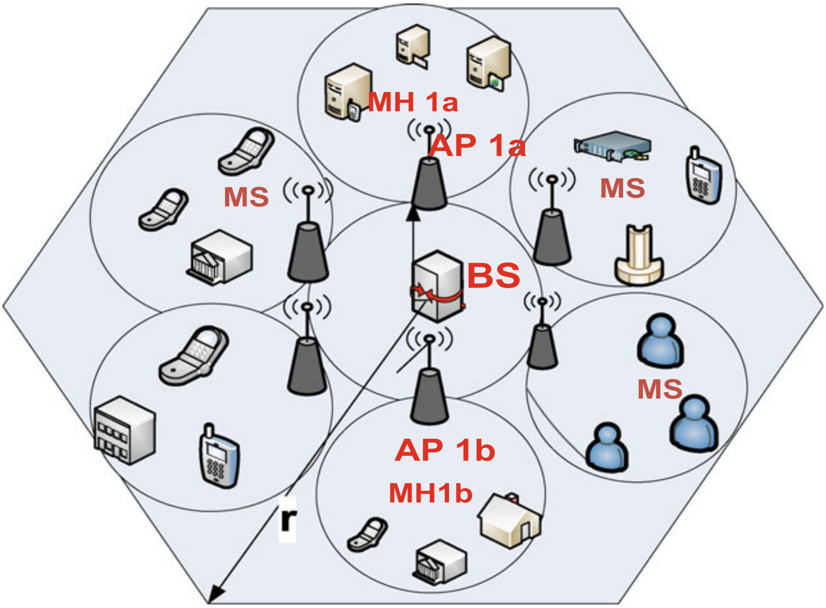


Fig. 2 CASHeW: Two-hop cluster-based architecture in a single cell (*hexagon*) scenario

The reusability of the available spectrum resource (time slot in a TDMA system and a frequency band in an FDMA system) is increased in the cluster-based design by allowing two multihop clusters in any cell to utilize the same spectrum resource [24]. For example, Fig. 2 shows how the clusters MH1a and MH1b are located at diametrically opposite sides of the BS. One can visualize that under the *Protocol Model*, AP1a can download to any MS in its cluster (maximum transmission between AP1a and its MS of the same cluster is $r/2$) using a given spectrum resource, and the BS could download to AP1b that is located at a distance of r from AP1a, in the opposite cluster of the same multihop cell. Hence, two communicating pairs in the given cell utilize the same spectrum resource. In fact, this idea has also been extended to a multi-cellular network design where the given resource is not only used *twice* in the same cell but also by two different pairs in every cell in the network, thereby ensuring a frequency reuse ratio of *one* in the wireless network. In a recent paper [25], the authors have analyzed mathematically and also observed through simulations that the prominent source of interference is always the intra-cell interferer. One should note that the number of clusters per cell in the cluster-based design need not be always six, though six has been found to be the optimum value for a cellular network [26]. It could be two, four, six, eight, ten or higher. However, it should be noted that the number of clusters per unit area has to be an "even" number due to the basic principle of simultaneous transmission of communication pairs located in the diametrically opposite clusters noted that the cluster-based mechanism in CASHeW could be further analyzed, especially in terms of maintaining the clusters, the selection of cluster heads (i.e., the access points) and dynamically changing the cluster-heads.

The cluster-based architecture illustrated in Fig. 2 has three main advantages. First, a cluster network facilitates the spatial reuse of resources within a coverage area which in-turn increases the system capacity and the aggregate data rate. The second benefit is in routing, where a heterogeneous cluster-based design with a central entity simplifies the selection of

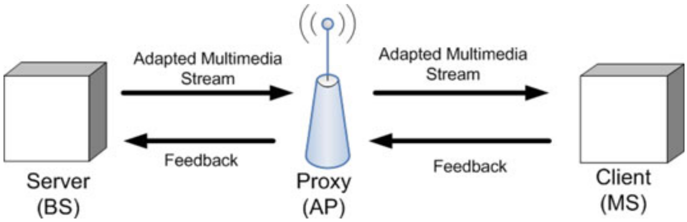


Fig. 3 Client-proxy-server architecture for feedback based delivery of multimedia data

the cluster-heads. Finally, a cluster-based design makes a multihop wireless network appear smaller and more stable from the perspective of a mobile terminal [27]. It should be noted that the cluster-based mechanism in CASHeW could be further analyzed, especially in terms of maintaining the clusters, the selection of cluster heads (i.e., the access points) and dynamically changing the shape of the clusters with the incoming or outgoing of wireless devices. However, these detailed architectural issues of the cluster-based design are beyond the scope of this paper. A detailed state-of-the-art explanation on the cluster-based design can be found in [12,24,28].

The primary aim of integrating an adaptive scheme for cluster-based design is to maintain a high end-user perceived video quality (Q) even with an increase in the number of wireless devices in the network. The basic idea is to vary Q in a controlled manner while maintaining continuity in the streaming process [22]. During downlink, the BS acts as a server whereas the MSs become the end-user clients that compute the quality of delivery of the received stream. During uplink, BS acts as a client that computes the quality of delivery of the received stream and the MSs act as servers which have a feedback-based traffic controlling mechanism. Since the AP lies between the BS and MSs in the end-to-end link, it acts as both client and server in both uplink and downlink. An illustration of the adaptive scheme deployment on two-hop architecture for downlink transmission is shown in Fig. 3. The proxy acts as client for the BS and as a server for the end-users. The client-server configuration can be similarly derived for the uplink mode.

3.2 Quality-Oriented Adaptive Mechanism for Multimedia Delivery

CASHeW enhances QOAS with support for enabling multihop adaptive multimedia delivery. It employs QOAS's client-side multimedia quality of delivery monitoring mechanism Quality of Delivery Grading Scheme (QoDGS) and server-side Server Arbitration Scheme (SAS). The former monitors the transmission quality and regularly computes Quality of Delivery (QoD) scores, which are used in the feedback mechanism to inform the server. SAS receives these grades and takes adaptation decisions. A quality state model was defined for the multimedia delivery process such that a particular stream quality is assigned for each state. These qualities differ in terms of bitrate (i.e. frame-rate, resolution or color depth), but also in the consequently expected user perceived quality [29], but they refer to the same multimedia content. A five state model is illustrated in Fig. 4.

When there is a decrease in the client-reported quality of delivery, the server switches to lower quality states hoping that by reducing the transmitted rate, the pressure on the delivery network will reduce and consequently lower loss will be achieved, increasing the actual user perceived quality. When there is an increase in the reported perceived quality,

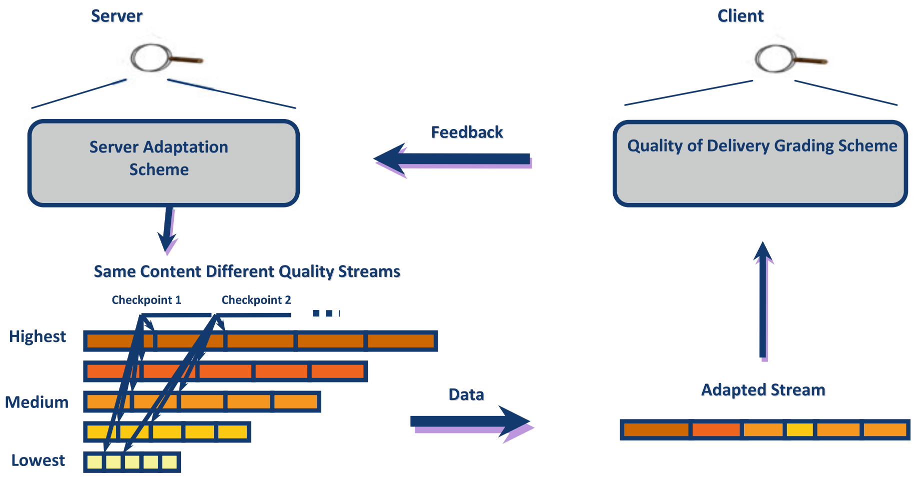


Fig. 4 Adaptive client-server based multimedia streaming mechanism

the server assumes that there is available transport capacity within the network and switches to higher quality states, increasing the multimedia delivery rate which, in the absence of loss, determines a user perceived quality increase. During up-scale or down-scale in the stream quality, the streaming rate is varied, helping the network to either recover from congestion or carry higher amounts of data and therefore improve the quality of transmission, respectively.

3.2.1 CASHeW—Quality of Delivery Grading Scheme (QoDGS)

The QoDGS at the client side monitors both short-term and long-term variations of packet loss rate, delay and delay jitter thereby evaluating the effect of the delivery conditions on end-user perceived quality. Short-term variations of parameters are monitored in order to learn quickly about the problems like sudden traffic changes that may affect the quality of delivery, whereas long-term monitoring considers the effect of changes in the delivery conditions such as increase in the number of new users and different network environments, thereby, introducing a degree of stability in the grading algorithm. There are three stages in the QoDGS grading mechanism. In the first stage, QoDGS regularly records the received stream's quality of delivery by considering each monitored parameter as well as end-user quality as measured by the multimedia quality metric Q [29], which maps the joint impact of bit-rate and data loss on video quality onto the ITU-T R P.910 five-point grading scale [30]. In the second stage, partial weighted scores that reflect the values and the variations of the monitored parameters are used to compute short-term and long-term quality of delivery grades. In the third stage, these scores are combined to determine an overall quality of delivery score (QoDscore). These final QoDscores are regularly sent to server. More details about QoDGS are presented in [22].

CASHeW requires full QoDGS modules both at the server (BS) and in the proxy (AP) for uplink traffic and both at the proxy (AP) and the client (MS) for the two-hop adaptive multimedia delivery.

3.2.2 CASHeW—Server Arbitration Scheme (SAS)

The server-located SAS assesses the value of a number of consecutive QoDscores received as feedback in order to reduce the effect of noise in the adaptive decision taking process. The SAS suggests server quality state adjustment decisions based on the QoDscore. This process is designed such that it requires fewer QoDscores to trigger a decrease in the server's quality state than for an increase. This is done in order to ensure a fast reaction during bad delivery conditions. However, the increase in the quality is done slowly as compared to the decrease in quality and is performed only when there is enough evidence that the network conditions have improved. This asymmetry helps also to maintain system stability, by reducing the frequency of quality variations [13].

CASHeW requires a slimmer version of SAS at proxy (AP)-side for both uplink and downlink traffic as the actual adaptation decisions are taken at the MS and BS, respectively. In fact the adaptation decision is taken at the level of AP based on the feedback received, but instead of applying it at the proxy state, the decision will be sent to the server as feedback. The server (MS or BS in uplink or downlink, respectively) employs a more complex version of SAS which takes its own adaptive decision based on the feedback received from the proxy. This decision is compared with that taken by the proxy and received by the sender via feedback and a final decision will be made to switch the server to the lowest quality state among the two. This enables a stream with a lower bitrate to be sent across the two hops to the receiver.

4 Performance Evaluation

4.1 Simulation Topologies

In case of multimedia transmissions, a server acts as the multimedia source that transmits multimedia content to all wireless devices in its coverage area. The end-users are the clients which receive the multimedia information over an IEEE 802.11 g network. Figure 5 shows a dumbbell topology considered in the performance evaluation for the single-hop homogeneous network scenario, wherein S0 is the multimedia source and S1, S2, …, SN the background traffic senders which transmit information to the N clients C0, C1, C2, . . ., CN via the BS. The links between S0, S1, S2, …, SN and BS are sufficiently provisioned not to cause any delays or loss. Figure 6 shows the two-hop heterogeneous wireless communication infrastructure (double-dumbbell topology), in which there is an intermediate relay denoted AP between the sources and clients. S0 and C0 exchange multimedia traffic using different solutions whose performance will be assessed, whereas S1, S2, …, SN and C1, C2, …, CN exchange background traffic, respectively.

4.2 Simulation Setup

The simulation setup consists of a number of mobile nodes distributed in the given coverage area. There is a sender located at the center of the coverage area. In case of a one-hop homogeneous network, the server communicates directly with all the wireless terminals in the network. However, in case of the cluster-based two-hop design, there are six gateways/relays across the coverage area, as shown in Fig. 2. The BSs/ routers of different cells/ regions have

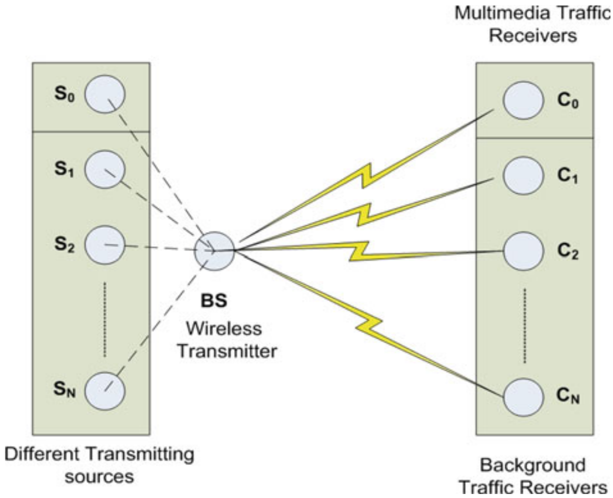


Fig. 5 Dumbbell network topology for single-hop client-server wireless architecture

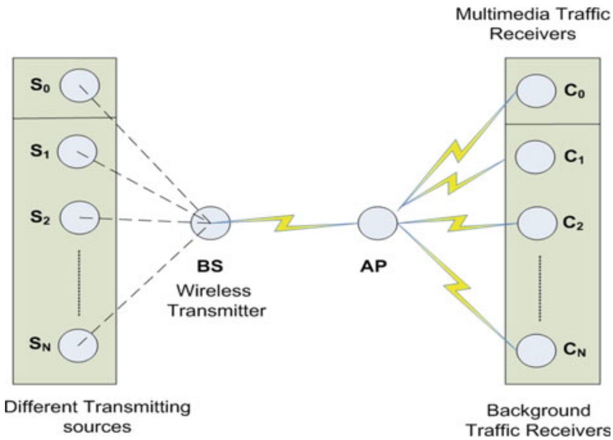


Fig. 6 Double dumbbell network topology for two-hop heterogeneous networks

a wired link between them (100 Mbps). Hence, a hierarchical structure exists between the server, the relays and the MSs, as shown in Fig. 2.

The system is simulated using server and client model instances built using Network Simulator version 2.31 (NS-2) [31]. In order to maintain uniformity, the length of all NS-2 simulations is kept at 200s. A binary phase shift keying (BPSK) modulation technique is considered at the physical layer. The heterogeneous environment for real-time multimedia streaming is restricted to a TDMA-based 3 G system and 802.11 g standard across the two-hops. A TDMA based UTRA-TDD (UMTS Terrestrial Radio Access in Time Division Duplexing) system is considered for communication between the BS and AP; whereas an 802.11 g standard is considered for communication between the AP and the end-users. The access point has functionalities similar to the F59333G SOHO router that implements seamless connection between public wide area networks (UMTS in our case) and IEEE 802.11 networks [32]. A slow-varying flat-fading channel is assumed

Table 1 Average perceived quality in case of CBR over UDP periodic background traffic

Size of periodic traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
1 × 0.6 20s ON–40s OFF	4.21	3.81	3.81	3.69	3.73	3.61	3.72	3.62	3.67
1 × 0.6 30s ON–60s OFF	4.03	3.69	3.72	3.42	3.53	3.49	3.62	3.46	3.48
1 × 0.8 20s ON–40s OFF	4.11	3.67	3.85	3.40	3.51	3.57	3.75	3.27	3.32
1 × 0.8 30s ON–60s OFF	3.87	3.31	3.58	3.01	3.01	3.21	3.58	3.01	3.02
1 × 1.0 20s ON–40s OFF	3.98	3.31	3.81	3.12	3.14	3.28	3.61	2.94	2.96
1 × 1.0. 30s ON–60s OFF	3.69	3.26	3.51	3.08	3.12	3.16	3.41	2.82	2.83

between the Tx–Rx pair across both the hops, throughout all the simulations. In addition, a lognormal shadowing of 4 dB standard deviation is considered throughout the analysis [33]. At the MAC layer, an IEEE 802.11-based distributed coordination function (DCF) is used.

4.3 Multimedia Traffic

Multimedia streams (audio and video) are transmitted over the one-hop and two-hop hierarchical wireless environment. In order to have an efficient transmission, the video signals are compressed using MPEG-4 [34]. A GOP with parameters $N = 9$ and $M = 3$ was used (i.e. the IPB structure was IBBPBBPBB), where N is the distance between two successive I-frames and M is the distance between I and the subsequent P-frames or between two successive P-frames [35]. The traffic used in this paper was generated to resemble the encoding of a news broadcast from the BBC at a frame rate of 30 frames/sec which generates 128 kbps for a typical picture phone image (1.3 Mega pixels). In these conditions, a picture varies between about 500 and 5,000 bits (with an average of 2,000 bits) which is within the range of an acceptable packet size for the IEEE 802.11LAN [36]. The MPEG4 traffic was generated using the Transform Expand Sample (TES) methodology developed in [37] and incorporated into NS-2.31.

4.4 Scenarios, Assessment and Results

The performance of CASHeW is evaluated when sending a multimedia stream as described in Sect. 4.2, while background traffic of different types and patterns is delivered over the same network. This includes UDP (CBR periodic and CBR increasing and decreasing in staircase-like manner) and TCP (FTP—long term file transfer-like and HTTP—WWW short-term bursty traffic) as explained in [38]. Different sizes and shapes are considered so as to emulate real life scenarios of various traffic sources with different average bit rates.

The simulation is done at the packet level and the performance of CASHeW is analyzed in terms of perceived quality, loss rate and average throughput, and compared with that when other solutions are employed. LDA+, TFRCP, RBAR and EDCA are used in turn for delivering multimedia over one-hop homogeneous and cluster-based two-hop heterogeneous networks, respectively. The end-user perceived quality is estimated using an equation which considers coding bitrate, throughput and loss ratio [39]. The results are shown in Tables 1–9 respectively.

Table 2 Average bit rate in case of CBR over UDP periodic background traffic

Size of periodic traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
1 × 0.6 20s ON–40s OFF	0.73	0.72	0.72	0.70	0.71	0.71	0.71	0.70	0.71
1 × 0.6 30s ON–60s OFF	0.73	0.72	0.72	0.71	0.72	0.71	0.72	0.72	0.72
1 × 0.8 20s ON–40s OFF	0.75	0.72	0.73	0.73	0.73	0.74	0.73	0.73	0.73
1 × 0.8 30s ON–60s OFF	0.75	0.72	0.73	0.73	0.73	0.74	0.73	0.74	0.73
1 × 1.0 20s ON–40s OFF	0.81	0.78	0.79	0.77	0.78	0.76	0.77	0.76	0.76
1 × 1.0. 30s ON–60s OFF	0.81	0.79	0.79	0.78	0.784	0.77	0.77	0.76	0.76

Table 3 Average loss rate in case of CBR over UDP periodic background traffic

Size of periodic traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
1 × 0.6 20s ON–40s OFF	0.08	0.12	0.38	0.18	0.24	0.20	0.42	0.22	0.26
1 × 0.6 30s ON–60s OFF	0.08	0.12	0.38	0.18	0.24	0.18	0.42	0.20	0.24
1 × 0.8 20s ON–40s OFF	0.04	0.16	0.34	0.16	0.20	0.16	0.40	0.18	0.20
1 × 0.8 30s ON–60s OFF	0.04	0.16	0.34	0.16	0.20	0.16	0.38	0.16	0.19
1 × 1.0 20s ON–40s OFF	0.01	0.10	0.21	0.12	0.18	0.14	0.24	0.14	0.16
1 × 1.0. 30s ON–60s OFF	0.01	0.10	0.21	0.12	0.18	0.14	0.24	0.14	0.16

Table 4 Average perceived quality for over CBR over UDP staircase-like background traffic

Size of staircase traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
4 × 0.4 (UP 40 steps)	4.30	3.83	4.09	3.72	3.92	3.58	3.68	3.48	3.56
4 × 0.8 (UP 40 steps)	4.12	3.67	3.92	3.48	3.56	3.48	3.67	3.17	3.34
4 × 1.0 (UP 40 steps)	4.06	3.63	3.86	3.24	3.34	3.17	3.49	3.00	3.24
4 × 0.4 (DOWN 40 steps)	4.10	3.59	3.80	3.14	3.62	3.20	3.57	2.95	2.84
4 × 0.8 (DOWN 40 steps)	3.96	3.44	3.66	3.00	3.44	2.87	3.56	2.78	2.89
4 × 1.0 (DOWN 40 steps)	3.83	3.33	3.63	2.95	3.01	2.68	3.32	2.67	2.78

Table 5 Average bit rate for CBR over UDP staircase-like background traffic

Size of staircase traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
4 × 0.4 (UP 40 steps)	0.76	0.72	0.74	0.72	0.73	0.68	0.71	0.67	0.69
4 × 0.8 (UP 40 steps)	0.81	0.78	0.78	0.76	0.77	0.72	0.74	0.71	0.72
4 × 1.0 (UP 40 steps)	0.81	0.79	0.76	0.75	0.76	0.73	0.74	0.72	0.73
4 × 0.4 (DOWN 40 steps)	0.74	0.68	0.68	0.67	0.68	0.74	0.75	0.73	0.73
4 × 0.8 (DOWN 40 steps)	0.79	0.76	0.76	0.70	0.71	0.80	0.81	0.76	0.78
4 × 1.0 (DOWN 40 steps)	0.81	0.80	0.80	0.72	0.73	0.81	0.80	0.80	0.80

Table 6 Average loss rate for CBR over UDP staircase-like background traffic

Size of staircase traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
4×0.4 (UP 40 steps)	0.04	0.08	0.24	0.08	0.10	0.26	0.46	0.24	0.26
4×0.8 (UP 40 steps)	0.00	0.03	0.18	0.14	0.16	0.18	0.42	0.20	0.24
4×1.0 (UP 40 steps)	0.00	0.04	0.18	0.10	0.12	0.18	0.40	0.18	0.19
4×0.4 (DOWN 40 steps)	0.06	0.10	0.16	0.12	0.14	0.18	0.28	0.18	0.19
4×0.8 (DOWN 40 steps)	0.01	0.04	0.14	0.12	0.14	0.14	0.24	0.16	0.18
4×1.0 (DOWN 40 steps)	0.00	0.03	0.14	0.12	0.12	0.13	0.24	0.16	0.18

Table 7 Average perceived quality for HTTP and—FTP over TCP as background traffic

Size of traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
$50 \times$ FTP (200s)	4.11	3.81	4.00	3.69	3.62	3.61	3.90	3.51	3.48
$54 \times$ FTP (200s)	3.97	3.67	3.90	3.42	3.62	3.47	3.72	3.30	3.46
$58 \times$ FTP (200s)	3.80	3.50	3.71	3.40	3.46	3.30	3.61	3.28	3.42
$40 \times$ HTTP (200s)	4.81	4.41	4.59	3.01	3.23	4.20	4.39	2.75	2.93
$50 \times$ HTTP (200s)	4.56	4.26	4.36	3.12	3.09	4.06	4.16	2.66	2.72
$60 \times$ HTTP (200s)	4.16	3.86	4.06	3.08	3.28	3.68	3.92	2.80	2.91

Table 8 Average bit rate with HTTP and—FTP over TCP as background traffic

Size of traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
$50 \times$ TP (200s)	0.76	0.73	0.72	0.70	0.71	0.71	0.71	0.69	0.70
$54 \times$ FTP (200s)	0.79	0.75	0.74	0.72	0.73	0.73	0.72	0.71	0.71
$58 \times$ FTP (200s)	0.81	0.76	0.76	0.75	0.75	0.75	0.73	0.73	0.74
$40 \times$ HTTP (200s)	0.71	0.70	0.70	0.71	0.77	0.69	0.68	0.70	0.70
$50 \times$ HTTP (200s)	0.72	0.71	0.72	0.71	0.77	0.70	0.70	0.70	0.70
$60 \times$ HTTP (200s)	0.78	0.73	0.75	0.76	0.76	0.71	0.74	0.76	0.76

Table 9 Average loss rate with HTTP and FTP over TCP as background traffic

Size of traffic (Mbps)	Two-hop heterogeneous network					Single-hop homogeneous network			
	CASHeW	TFRC	LDA+	RBAR	EDCA	TFRC	LDA+	RBAR	EDCA
$50 \times$ FTP (200s)	0.01	0.10	0.10	0.10	0.09	0.14	0.20	0.18	0.2
$54 \times$ FTP (200s)	0.01	0.10	0.10	0.12	0.11	0.14	0.20	0.22	0.23
$58 \times$ FTP (200s)	0.04	0.12	0.14	0.12	0.12	0.14	0.18	0.22	0.24
$40 \times$ HTTP (200s)	0.01	0.04	0.11	0.14	0.13	0.14	0.14	0.24	0.26
$50 \times$ HTTP (200s)	0.01	0.04	0.12	0.14	0.13	0.14	0.14	0.24	0.27
$60 \times$ HTTP (200s)	0.05	0.09	0.15	0.12	0.14	0.19	0.18	0.18	0.24

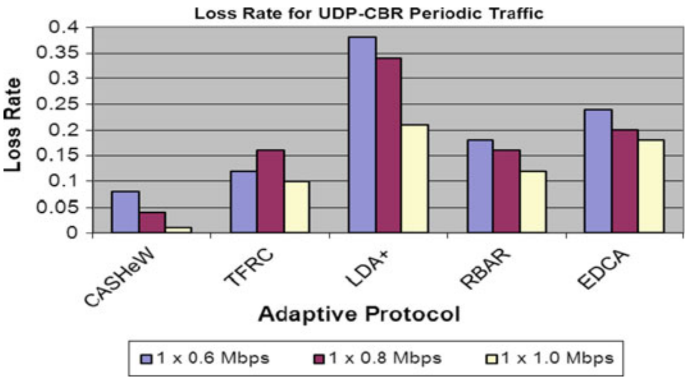


Fig. 7 Average loss rate for different protocols in case of UDP-CBR periodic traffic

4.4.1 UDP CBR Periodic

Tables 1, 2 and 3 present the performance results when CASHeW, TFRCP, LDA+, RBAR and EDCA schemes are used to deliver multimedia traffic in parallel with CBR over UDP background traffic which exhibits a periodic variation. The periodic background traffic is generated at 0.6, 0.8 and 1 Mbps with two different patterns: 20s-on-40s-off and 30s-on-60s-off. It can be observed that for the delivery over the two-hop wireless network with 1×0.6 Mbps CBR background traffic with 20s-on-40s-off period, the average estimated end-user perceived quality of CASHeW is 4.21, whereas that of other solutions in this case is: 3.81 (TFRCP), 3.81 (LDA+), 3.69 (RBAR) and 3.73 (EDCA). Looking at Table 1, it can be observed that regardless of changes in the background traffic rate and periodicity, the average end-user perceived quality of CASHeW is significantly superior to the other methods. Additionally, it can be seen clearly in Table 1 (and in all the subsequent Tables), that the performance of all solutions employed are superior in case of a two-hop architecture as compared to that of the same solution when employed to deliver multimedia over a single-hop infrastructure.

Tables 2 and 3 show how the performance of CASHeW is compared against other methods in terms of the average throughput and loss rate, respectively. The loss rate results are also shown in Fig. 7 for two-hop network employing double dumbbell topology. It can be observed that for all 3 background traffic patterns in this category (1×0.6 Mbps, 1×0.8 Mbps and 1×1.0 Mbps), the loss rate of CASHeW is the lowest of all, whereas that of LDA+ is the highest. Table 3 indicates another significant point, i.e., the loss rate remains constant (for all protocols) when the periodicity is varied while keeping the background traffic rate the same. Also, when the background traffic is varied, the loss rate changes accordingly independent of the periodicity. This indicates that the loss rate depends only on the background traffic and does not depend on the periodicity, so it can be concluded that well statistically multiplexed start-stop events of concurrent streaming sessions have no influence on the multimedia delivery quality.

4.4.2 UDP CBR Staircase

In the case of CBR over UDP with staircase-like background traffic, there is a stepwise variation (increase or decrease) in the bitrate of the background traffic every 40s. In addition, the rate either goes up or down in steps of 0.4 Mbps. For example, 0.3 Mbps 40s-up in Table 2 indicates that a bit rate of 0.3 Mbps is increased by 0.4–0.7 Mbps, then to 1.1 Mbps after additional 40s, etc. This simulates other multimedia streams joining or leaving the network. Tables 4, 5 and 6 show the results in terms of average perceived quality, average throughput and loss rate respectively in this situation. It can be observed across all the rows in these tables that CASHeW significantly outperforms other adaptive solutions over the two-hop wireless environment. Figure 10 shows the results for end-user perceived quality in case of 4×0.4 Mbps traffic with 40 steps for both increase (UP) and decrease (DOWN) in background traffic. It can be observed from Fig. 8a that in the UP case, the perceived quality in case of CASHeW is 4.30 and is 12.1% higher than that of TFRCP (3.83), 4.93% higher than that of LDA+ (4.10), 15.51% higher than that of RBAR (3.72) and 9.6% higher than that of EDCA (3.92). It can also be observed from Fig. 8b that in DOWN case, the improvement in the performance of CASHeW is even better. The estimated end-user average perceived quality for CASHeW is 4.10 which is 13.93% higher than that of TFRCP (3.60), 7.76% higher than that of LDA+ (3.80), 30.32% higher than that of RBAR (3.14) and 13.1% higher than that of EDCA (3.62). It should also be noted that the performance of all these protocols (LDA+, TFRCP, RBAR and EDCA) are superior in case of two-hop architecture than that of the same solutions used over a single-hop network.

An important point is that the loss rate of CASHeW is extremely low (in the range of 0.00–0.06) whereas that of other protocols are considerably higher Notably though the perceived quality of LDA+ is only 5–10% less than that of CASHeW the loss rate of LDA+ is significantly higher (in the range of 014–024) In fact the loss rate of LDA+ is the highest of all other protocols This justifies why LDA+ is not a preferred solution.

4.4.3 TCP FTP

In this case TCP is considered as background traffic with FTP (long-term file transfer) and HTTP (short-term WWW traffic) scenarios. The performance results are shown in Tables 7, 8 and 9, respectively. Figure 9a, b compare the perceived quality of CASHeW with other solutions regardless of the FTP and WWW background traffic employed, respectively. An important point to be noted from both Fig. 9a, b is that the average perceived quality of CASHeW consistently remains better than that other protocols when employing the double dumbbell topology. In addition, in case of double dumbbell topology, it can be observed from Fig. 10 that for different FTP traffic, the loss rate of CASHeW has a very low value as compared to that of other protocols, i.e., TFRCP, LDA+, RBAR and EDCA.

4.5 Extension to General Multihop Networks

A significant point to be noted is that there are two components of CASHeW that would have to be modified while designing for a generalized hierarchical multihop architecture. The first component is the distribution of client-server adaptive scheme across several hops. This is a relatively easy task. In a higher number of multiple hops, the functionality of the proxy-client-server can be distributed across several intermediate relay nodes with each relay node acting as client or server, depending upon whether the data is being transmitted in uplink or downlink mode. Additionally,

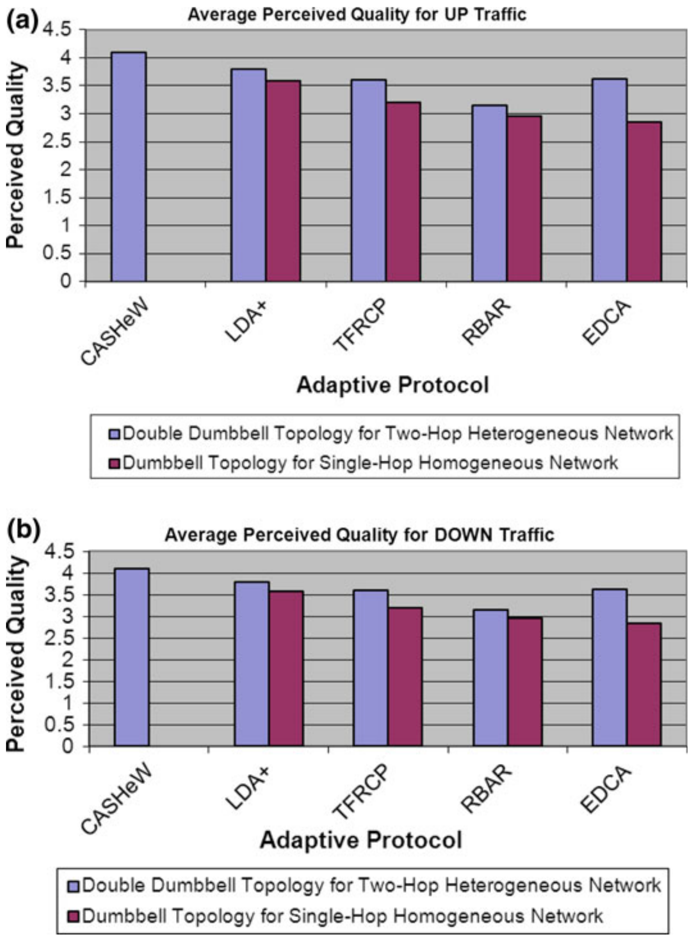
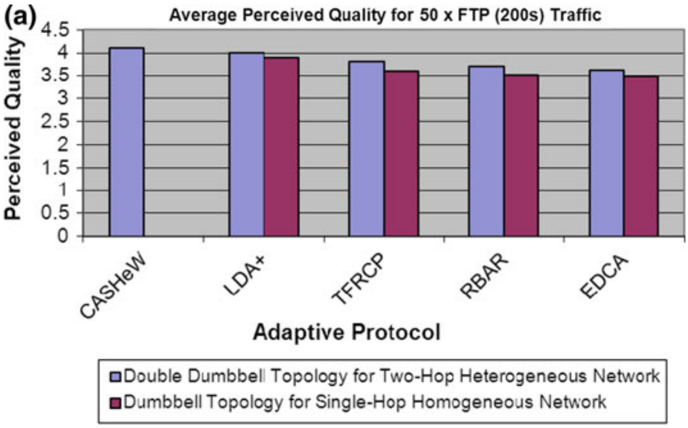


Fig. 8 **a** Average perceived quality for different protocols in case of UDP-CBR staircase UP traffic (UP 40 steps). **b** Average perceived quality for different protocols in case of UDP-CBR staircase DOWN traffic (DOWN 40 steps)

the quality-oriented adaptive scheme can be implemented over each hop, in order to maintain the optimum video quality at every stage of the network, though this might result in some delay. However, the second component in generalizing CASHeW to higher number of multiple hops is the design of the cluster-based architecture. An upgradation of the cluster-based design from even two to three hops would result in an extremely complex system—two layers of clusters, with six and twelve clusters respectively, in a single cell. Hence, for a three-hop network, there would be 18 clusters in every cell and in a four-hop scenario, there would be 36 clusters in any cell. The formation of the clusters, the selection of cluster-head and maintenance of the clusters in a mobile environment are highly complicated and challenging tasks that hinder the design and implementation of the cluster-based design for general hierarchical multihop networks.



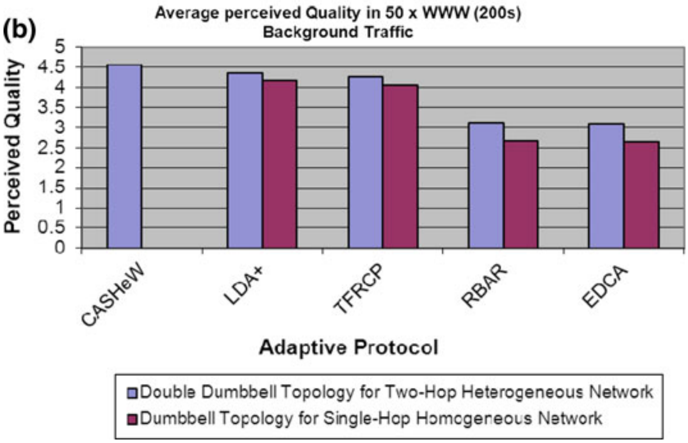


Fig. 9 **a** Average perceived quality for different protocols in case of 50 × FTP (200s) background traffic. **b** Average perceived quality for different protocols in case of 50 × FTP (200s) background traffic

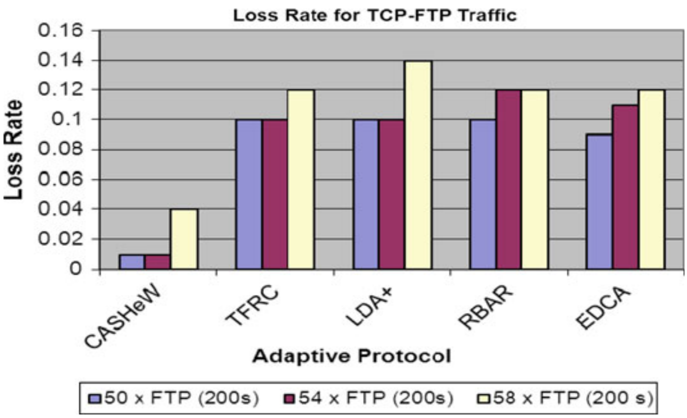


Fig. 10 Average loss rate for different protocols in case of TCP-FTP traffic

5 Conclusions

This paper proposes CASHeW, the cluster-based adaptive scheme for multimedia delivery in heterogeneous wireless networks, which makes use of a resource-efficient cluster-based architecture to delivery wirelessly adaptive multimedia. There are two main advantages of CASHeW. Firstly, the cluster-based architecture, with clients that are located diametrically opposite to the base station communicating simultaneously, provides a frequency reuse of *one* in the wireless network, increasing the efficiency of transmission. Secondly, CASHeW adapts the bit-rate of multimedia transmissions in a controlled manner depending on the automatic feedback received from the client device over a two-hop infrastructure.

Extensive simulations and testing has demonstrated both superior multimedia quality in the two-hop heterogeneous networks compared to a single-hop design, and that CASHeW outperforms other transport layer adaptive solutions like TFRCP and LDA+ and MAC layer protocols like RBAR and EDCA in a cluster-based hierarchical two-hop wireless network environment. In addition, the loss rate is reduced when CASHeW is employed. These very significant results would encourage the network operators to make use of quality oriented adaptive schemes and implement the cluster-based solution in the design of next generation heterogeneous multihop wireless networks, in order to provide high quality multimedia streaming to the wireless end-users.

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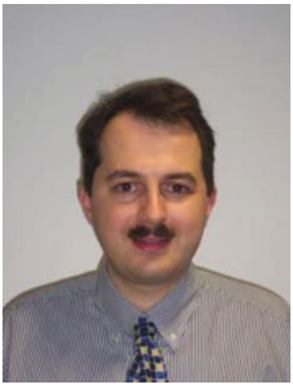

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