Mobile Multi-source High Quality Multimedia Delivery Scheme

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***Abstract*—Increasing amount of multimedia content is being delivered over heterogeneous networks to diverse user types, holding various devices, many of them mobile. Mobile devices such as smartphones and tablets have already become both consumers and sources of multimedia content, but the delivery quality varies widely, especially due to their users' mobility. In order to support increasing the quality of the multimedia content delivered to a growing number of mobile users, this paper introduces a Mobile Multi-source High Quality Multimedia Delivery Scheme (M3QD). M3QD supports efficient high quality multimedia content delivery to mobile users from multiple sources. Both simulations and prototyping-based perceptual tests show how increased user perceived video quality and improved mobility support is achieved when using M3QD in comparison with the case when a single source classic approach is employed. M3QD can be used in various scenarios involving multimedia content distribution between mobile users in leisure parks or around tourist attractions, content exchange between vehicles on urban roads and even information delivery in industrial applications where content has to be shared between large number or diverse mobile users.**

***Index Terms*—Multi-source Multimedia, User Mobility, Wireless Networks, Quality of Experience.**

I. Introduction

MULTIMEDIA content exchanged by mobile devices is increasing dramatically in terms of both number of streams and their quality as the expectations of users also increase. Mobile devices including smartphones and tablets are overtaking classic devices such as desktops in terms of the amount of multimedia content they store, process and share. For instance, the mobile video traffic accounted for 55 percent of total mobile data traffic in 2015 and it is estimated that will reach 75 percent by 2020 [1]. At the same time, cloud computing is already supporting a wide range of flexible innovative applications and services, many multimedia-based. Lately mobile cloud is adding another dimension to cloud computing flexibility: user mobility. This encourages further development of existing services and proposal on new and potentially highly attractive applications for the increasing user base.

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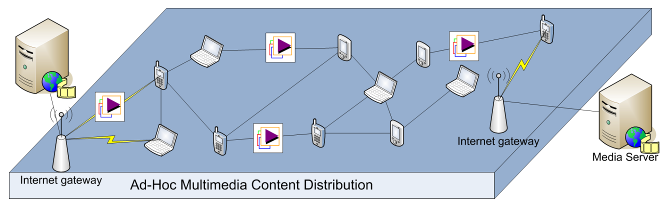

Fig. 1. Wireless network environment supporting mobile multimedia content distribution.

The highly popular social networking services for example are seeing an increased number of users sharing with peers multimedia content either originating from their mobile devices or previously received from media servers. Mobile users of such rich media communication-oriented applications possess increasingly sophisticated and capable portable devices, in terms of connectivity, processing and graphical display capabilities. Additionally, most mobile devices are already equipped with multiple wireless interfaces which allow them to connect simultaneously to multiple wireless networks using different wireless communication technologies (e.g. WiFi, LTE, etc.), enabling them also to form ad-hoc networks. Although not yet available on the market, mobile devices equipped with multiple interfaces on the same technology (i.e. WiFi) are already discussed and designed both in the academia and industry [2], targeting an even better mobile inter-connectivity.

In these circumstances, as illustrated in Fig. 1, hybrid networks combining the benefits of both ad-hoc and infrastructure-based communications are an appealing option for enabling efficient multimedia content delivery between mobile devices. However, wireless communications in general, and mobile multi-hop content delivery in particular, are well known for their bandwidth and latency-related limitations. Consequently, in this context, the biggest challenge is to support high quality multimedia content delivery.

This paper introduces a novel Mobile Multi-source High Quality Multimedia Delivery Scheme (M3QD) for high quality multimedia content distribution to mobile users over wireless networks. M3QD employs a multi-source multi-stream content delivery paradigm which stands at the basis of its flexibility, robustness and high quality of delivery. The proposed solution enables high quality multimedia content delivery, while also supporting user mobility.

The performance of M3QD is evaluated using both modeling and simulations, and perceptual-based real-life tests. M3QD is compared with a multimedia delivery approach where the content is transmitted from a single source. The comparative evaluation is made in terms of estimated user perceived video quality, assessed using both objective metrics and subjective methods.

The results show how the proposed M3QD solution outperforms consistently the classic single-source approach.

The structure of the paper is as follows: section II presents related works in terms of multimedia delivery solutions in general and multimedia content delivery mechanisms in particular. Most important video quality assessment metrics and techniques are also described. The proposed solution and its underlying architecture are presented in section III, which also details the major components, their interaction and the algorithms proposed. Section IV presents the modeling and simulation-based testing environment, scenarios and results obtained by objective assessment of M3QD's performance. It also describes the subjective perceptual quality assessment and its results following prototype-based testing. The paper ends with conclusions.

II. Related Work

This paper introduces a novel multi-source scheme for high quality multimedia content distribution to mobile cloud users. Various aspects related to multimedia content distribution and cloud-based solutions are discussed in this section, which also presents the most important video quality assessment methods and techniques.

A. Adaptive Multimedia Delivery

User satisfaction is crucial for the success of any multimedia-based application, including those involving network delivery. In terms of achieving high levels of user satisfaction with the multimedia delivery service, of paramount importance is supporting high multimedia quality levels. In order to avoid the negative impact dynamic network conditions have on multimedia quality, adjusting the delivery process to follow and match the available network bandwidth is required. If short term variations can be overcome by using buffering techniques [3], for long time-scale network dynamics, rate adaptation techniques are among the most efficient solutions.

Initially, basic loss and delay-based adaptive streaming solutions were proposed at network transport layer including the TCP-Friendly Rate Control Protocol (TFRCP) [4] and the enhanced Loss-Delay-based Adaptation algorithm (LDA+) [5]. These solutions present a reasonable performance in terms of Quality of Service (QoS), but their major drawback is a poor correlation with the actual end-user perceived quality.

Later on, more advanced adaptive delivery techniques which succeeded to maintain high levels of user perceived quality were developed at the application layer. Such a solution with good performance in terms of user perceived quality is the Layered Quality Adaptation algorithm (LQA) [6]. LQA performs the adaptation by adjusting the number of video quality layers transmitted to the viewers and consequently their expected perceived quality levels depending on their available network bandwidth resources. Cross layer adaptive video delivery methods are more efficient in terms of delivery-related information gathering and processing and tend to achieve higher user perceptual quality for the remotely watched multimedia content. A good survey of these solutions can be found in [7].

The Quality Oriented Adaptation Scheme (QOAS) [8] involves user perceived quality estimations in the feedback-based multimedia adaptation process. As it is quality-oriented, QOAS shows significant improvements in end-user perceived quality when used for streaming multimedia content in both wired and wireless networking environments.

Diverse techniques were proposed for adaptive multimedia transmissions over wireless access or ad-hoc networks. Among the proposed solutions are adaptation mechanisms at the level of layers [9] or objects [10], transmission protocols [11], fine-granular scalability schemes [12] and perception-based approaches [13].

An analytical model for end-to-end rich multimedia services delivered in network virtualisation environments that can be used to determine end-to-end bandwidth and delay performance bounds in virtual network has been presented in [14]. Both theoretical analysis and experimental results have demonstrated the applicability of the model for delivery of multimedia in various heterogeneous networking systems.

Region of Interest (RoI)-based adaptive schemes have been proposed including the ones introduced in [15], [16] and [17]. These solutions treat different parts of the overall image area distinctly in the adaptation process based on the user level of interest. More recently, Ruckert et al. [18] have proposed a quality adaptation scheme in peer-to-peer Scalable Video Coding (SVC)-based video streaming based on objective QoE metrics. The proposed adaptation strategies increase or decrease the video quality by selecting different coding layers during the video delivery in order to result in the highest QoE possible.

BitDetect [19] is a multimedia adaptation mechanism which uses objective video quality assessment metrics such as PSNR and SSIM to recommend specific video bitrate levels that enable battery saving while maintain good user perceived quality. Subjective tests have shown that the recommended bitrate thresholds for multimedia clips with various characteristics offer good user perceived quality. A video delivery solution which employs network selection and balances energy consumption and video quality was described in [20], whereas the video distribution mechanism described in [21] performs energy-quality and cost trade-off.

Khan et al. [22] have introduced a QoE driven adaptation scheme for video delivery over wireless networks, which employs a reference-free QoE model. This model estimates user QoE impact based on encoding frame rate, sender bit rate and packet error rate and informs the adaptation process.

Xu et al. [11] have proposed a highly innovative ant behavior-inspired solution for video delivery in wireless mobile networks based on creation and management of mini-communities.

For many years, server side streaming and multimedia adaptation have been proposed by different researchers [23]. Recently, HTTP adaptive streaming (HAS) has been introduced in different forms including Adobe's HTTP Dynamic Streaming (HDS) [24], Microsoft's HTTP Smooth Streaming (HSS) [25], and Apple's HTTP Live Streaming (HLS) [26] and is used for diverse Internet video applications such as YouTube. This new streaming approach requires the division of the video content in multiple quality level chunks, which are short video segments. The network condition (e.g. available bandwidth) and/or buffer status or other parameters are analysed at the client side and requests for video segments at appropriate quality levels are sent to the server, which delivers them. The existence of multiple quality video sequences enables better adaptation to the user demand and network conditions, higher bandwidth utilisation and fewer interruptions in the multimedia playback.

Oyman et al. [27] have presented an overview of HAS and HAS-specific cross-layer adaptation algorithms, which rely on tight integration of the HAS/HTTP-specific media delivery with network-level and radio-level adaptation and QoS schemes to determine optimum application, transport, network and radio configurations considering link, device and content, in order to result in highest possible user QoE.

A comprehensive survey on current HTTP adaptive streaming solutions and QoE of HTTP adaptive streaming is presented in [28].

B. Cloud-based Multimedia Content Delivery

In the context of this paper the mobile cloud is represented by the hybrid ad-hoc and infrastructure-based wireless network and the corresponding software components part of the system architecture, as described in Section III. In this context, various architectures, frameworks and algorithms have been proposed to provide efficient, flexible and high quality multimedia services to end users.

A multimedia-aware cloud-based solution was introduced in [29]. The authors perform distributed multimedia processing and storage and provide quality of service (QoS) provisioning for remote multimedia service users. The cloud-based software architecture for multimedia collaboration introduced in [30] allows users to perform video conferencing, while also viewing shared media content in real-time. Load balancing for cloud-based multimedia systems discussed in [31] considers the load of all servers and network conditions and targets optimal resource allocation and scheduling. A Personalised DTV Program Recommendation (PDPR) system deployed on a cloud computing environment is proposed in [32]. PDPR analyses the viewing pattern of users to personalise program recommendations, and to efficiently use computing resources.

The architecture for multimedia streaming on the hybrid Telco cloud proposed in [33] shows how operators can exploit their local presence and control the access network to add dynamically scalable communication to the cloud services.

C. Video Quality Assessment

Video quality assessment methods and metrics are used to assess the effects variable network conditions and mobility management have on user perceived quality.

A concise and up-to date analysis of current research on video quality assessment as well as a discussion on future trends and challenges regarding QoE assessment in multimedia streaming services is presented in [34].

Two main categories of video quality assessment can be identified: subjective methods and objective metrics [35].

Subjective testing involves human observers and follows methodologies and recommendations such as those from ITU-R BT.500 [36], ITU-T R. P.910 (one way video test methods) [37], ITU-T R. P.911 (quality assessment methods for multimedia applications) [38] and especially ITU-T R. P.913 (subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment) [39].

Considering the methodology used to present the multimedia clips to the subjects there are three approaches to perform the subjective video quality assessment: single stimulus, double stimulus and comparison stimulus. Detail description and comparison analysis of these approaches are presented in [34] and [40]. Although subjective based video quality assessment is the most accurate and reliable solution, as subjects are asked directly to grade the multimedia clip quality, it has some important drawbacks including high cost, is time consuming, requires controlled environment, and needs human subjects that are difficult to get in order to be fully representative for the entire population targeted. Due to the limitations of the subjective based video quality assessment approach, a high number of researchers have focused on proposing objective video quality assessment methods.

These objective video quality assessment methods are classified in [41] as out-of service methods (the original sequence is available and used during the assessment and no time constraints are imposed) and in-service methods (performed during video delivery without having the original video sequence and with strict time constraints).

From a different perspective [42] the objective methods can be classified into full reference methods (use comparisons with reference streams), reduced reference solutions (employ feature extraction) and no reference methods (no original stream is required for quality assessment). An in-depth state of the art description and comparison of various full reference, reduced reference and no reference-based methods is presented in [40].

Among the most important and widely used objective video quality metrics are the full-reference Peak Signal-to-Noise Ratio (PSNR) [43], Structural Similarity (SSIM) [44] and Video Quality Measurement (VQM) [45]. PSNR is based on signal variation only and has no relationship with the way humans see the video streams. SSIM is based on the idea that the human visual perception is adapted to extract mostly structural information. VQM is a metric that measures the combined effect of various factors such as blurring and blockiness on user perception of the video content.

Although objective video quality assessment methods are suitable for a wide range of applications and scenarios that require multimedia streaming and are used in both real and simulation use cases, there are a number of challenges that need to be considered. These challenges include the need for mapping the objective metric values into subjective MOS scale values, the requirement of the presence of the reference video

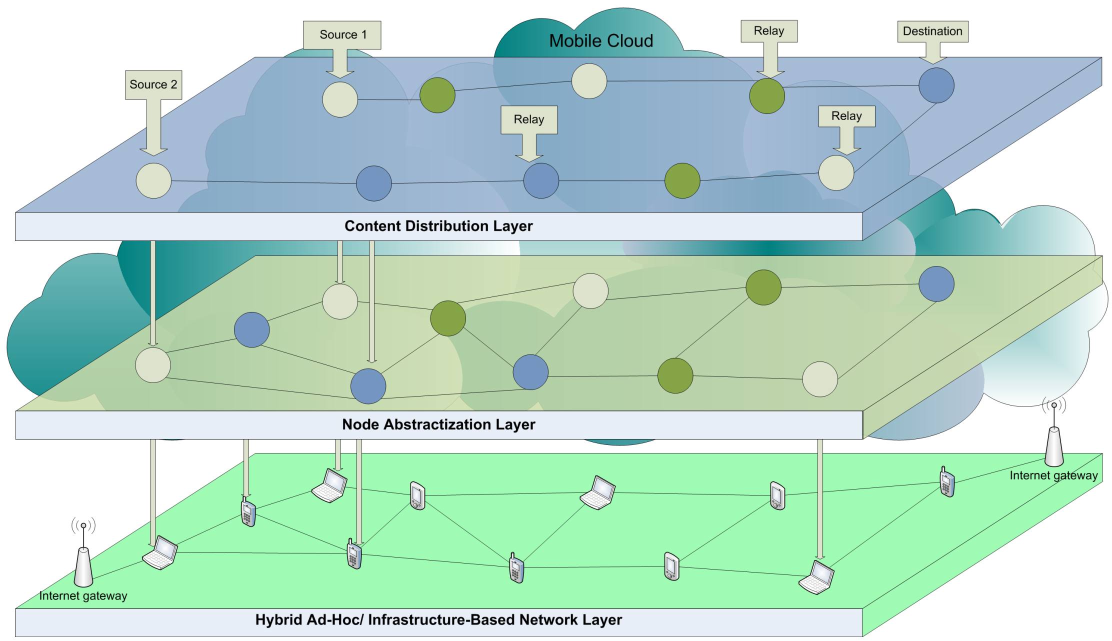

Fig. 2. System architecture for multi-source multimedia content delivery.

for full reference objective assessment (which makes the use of full reference metrics impossible for real-time video delivery) and the limited accuracy when subjective tests are performed on a limited set of data. Researchers have already addressed some of these challenges proposing innovative solutions such as for instance the quality mapping mechanism described in [46] that automatically creates generic rules for mapping the measured values of a given objective metric applied to a particular video to the subjective MOS scale.

III. Multi-source Multimedia Content Distribution - Architecture and Algorithms

A. System Architecture

The multi-source multimedia content is delivered over a mobile cloud architecture, as illustrated in Fig. 2. The architecture is composed of three distinct layers.

The first layer is the **Hybrid Ad-Hoc and Infrastructure-based Network** (or *Network*) layer. This layer consists of a hybrid network, composed of mobile devices capable of communicating with each other in an ad-hoc manner and also with distant servers over infrastructure-based networks (i.e. 3G, WiMax).

The *Network* layer relies on existing communication technologies and protocols such as ad-hoc routing algorithms and transport protocols and represents the basis for mobile cloud system deployment. It includes all the basic mobile device hardware and software components such as communication interfaces, processors, storage and includes operating systems.

The second layer is the **Node Abstractisation** layer and is part of the cloud infrastructure. This *Node Abstractisation* layer is in charge with building and maintaining a set of abstract entities describing the mobile devices and distant servers in terms of their role (i.e. mobile content provider, remote content provider, cluster head, transport relay). It represents the basis for content advertising and multi-source content delivery strategies.

The third architectural layer is the **Content Distribution** layer. This layer receives content requests from mobile entities, selects appropriate content sources and manages content delivery and adaptation. The sources are initially selected based on content availability and then are managed dynamically along with the streaming process in order to maximize efficiency and delivery quality.

The software components of the mobile cloud architecture as deployed at the device level are presented in Fig. 3 and are described in the following sections.

B. Abstractisation Process and Content Source Management

The *Node Abstractisation* layer of the mobile cloud architecture consists of a set of entities representing mobile devices organised in a hierarchical manner as illustrated in Fig. 4.

This abstract hierarchy is composed of three sub-layers: *Basic Device Entity*, *Cluster Head* and *Main Distribution Servers*. These sub-layers are described next.

The **Basic Device Entity** is the lowest sub-layer in the hierarchy. It contains virtual entities representing the mobile devices, entities which are associated with capabilities and content available on their associated devices. Each virtual entity stores a unique device ID (e.g. IP address) based on which the device may be accessed via the network. The information about device capabilities and content stored present in the virtual entity is described using the Resource Description Framework (RDF) [47] specifications.

The **Cluster Head** sub-layer is in charge with organising the entities in virtual clusters. These virtual clusters are not in any way related to the ad-hoc network clusterisation and do not take part in routing. Virtual cluster formation and head election (Cluster Manager) employs the algorithm presented in

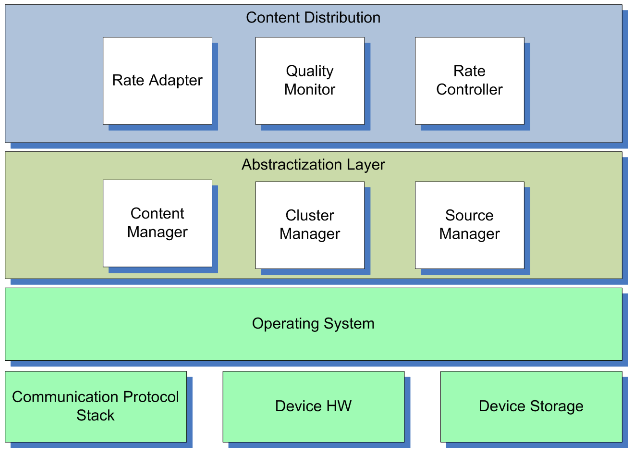

Fig. 3. Software components for system architecture.

[48] to control the number of hops between each node and its cluster head. The performance of this algorithm has a major impact on content information dissemination. However any other clusterisation algorithm which maintains low the number of hops can be used.

The **Main Distribution Servers** sub-layer is composed of entities associated with the remote media distribution servers which are used as alternative sources for the media content by the proposed mobile cloud-based content distribution solution.

Fig. 3 illustrates the software components of the cloud architecture and *Content Manager* and *Source Manager* correspond to the *Node Abstractisation* layer. Their functionality is described next in the context of content source management and cluster operation.

The content source management process consists of two main tasks: content information update and content source retrieval. The content information update refers to the management of information about the devices and their media content and the **Content Manager** is in charge with it. The cluster heads maintain a list of all devices (i.e. in terms of their IDs) within their cluster footprint and a list of content available on each device. These lists are used for content search and source management.

Algorithm 1 presents the pseudo code of the **Content Information Update Algorithm** employed for content list creation and update. It can be seen how, when a new device joins a cluster, its relevant information regarding device identification and content is collected and stored in the corresponding lists at the cluster head level. Additionally, everytime new content is generated or acquired by the node, content-related information list is updated at the cluster head. From the cluster head point of view information gathering is a pull-based process in which the nodes contribute with the relevant data, except when a new node becomes cluster head and it requests data to refresh the information it has received from the previous head.

The content source retrieval is performed by the **Source Manager**. A mobile device requesting a certain content sends the request to its cluster head. The cluster head then broadcasts the request to other cluster heads. If a cluster head received the request for a content it has in its list, a response containing the IDs of the mobile devices storing the requested content is sent to the cluster head associated with the original request. The Source Manager component is required for maintaining the source pool from which the active sources are chosen according to their quality scores and traffic requirements and can reside at the level of either any basic node or the cluster head. The Source Manager component initiates connection requests to data sources. The inactive sources which are not capable of delivering at least a minimum bit-rate traffic are considered to be dead and are removed from the list.

Algorithm 1 Content Information Update.

Basic Node:
  if $Node\_Joined\_Cluster$ **then**
    $Send\_Update\_All\_To\_Head(Content\_List\_Size)$;
    $Send\_Content\_List\_To\_Head()$;
  end if
  if $New\_Content\_Received$ **then**
    $Send\_Update\_Content\_To\_Head(Content\_Info)$;
  end if
  if $Content\_Update\_Request\_From\_Head$ **then**
    $Send\_Update\_All\_To\_Head(Content\_List\_Size)$;
    $Send\_Content\_List\_To\_Head()$;
  end if
Cluster Head:
  if $New\_Cluster\_Head$ **then**
    for all $Node$ in $List\_Of\_Nodes$ **do**
      $Send\_Content\_Update\_Request\_To\_Node(Node)$;
    end for
  end if

Algorithm 2 Content Source Search.

Cluster Head:
  if $Content\_Request\_Received\_From\_Node$ **then**
    $Broadcast\_Content\_Request\_To\_All\_Heads()$;
  end if
  $Sleep(Wait\_Time)$
  if $Number\_Source\_Lists\_Received == 0$ **then**
    $Send\_To\_Node(Remote\_Server\_Id)$;
  else
    $Send\_To\_Node(Aggregated\_Source\_List)$;
  end if

Algorithm 2 presents the pseudo code of the **Content Source Search Algorithm**. It can be noted how the content request is broadcasted through the mobile cloud architecture and if no response is received, the content is fetched from the video server; otherwise the list of options is sent to the requesting node.

C. Content Delivery

Content delivery is performed by the Mobile Cloud-based Multi-source High Quality Multimedia Delivery Scheme (M3QD), which is deployed at the **Content Distribution** architectural layer and involves three activities: rate control, rate adaptation and content delivery quality monitoring. The

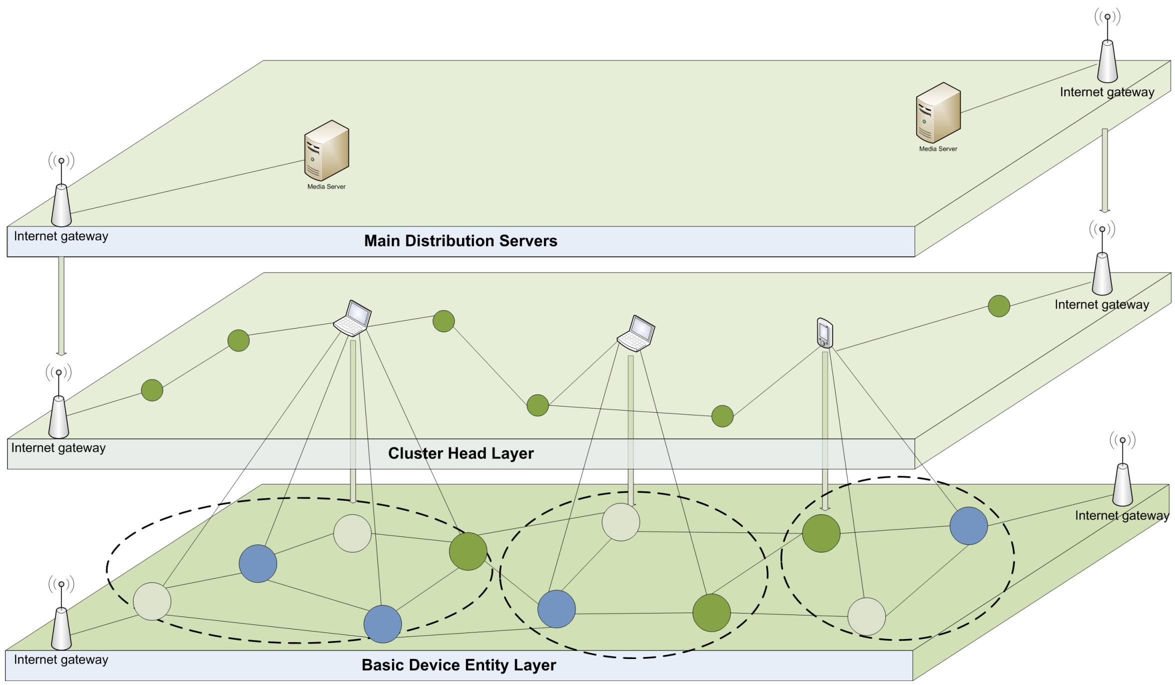

Fig. 4. Node Abstractisation Layer - hierarchical structure

software components in charge with these activies are Rate Adapter, Quality Monitor, and Rate Controller and are illustrated in the context of the mobile cloud-based layered architecture in Fig. 3. These components are described next along with the algorithms they employ.

The proposed cloud-based multimedia content delivery solution offers support for receiving content from multiple sources. For efficient traffic distribution and smooth mobility management, multi-source content delivery is achieved by scheduling the sources to send data at specified rates. Individual delivery rates are computed regularly by the **Rate Controller** according to the quality of delivery assessed at the destination, separately for each delivery path. The delivery is monitored by the **Quality Monitor** and each path's capacity to deliver high quality multimedia traffic is estimated using the Quality of Multimedia Streaming (QMS) metric proposed in [49].

QMS considers delivery-related aspects such as QoS, QoE, financial cost, power efficiency and user preference. As out of these, QoS and QoE only are relevant in the multi-source multimedia delivery context considered in this paper, QMS is computed for each delivery path i according to equation (1):

$$QMS^i = (QoS^i_{grade} + QoE^i_{grade})/2 \tag{1}$$

where the QoS^i_{grade} and QoE^i_{grade} represent grades which assess network QoS level and user estimated QoE share for communication channel i and are described by the formulae from equation (2) and equation (3), respectively.

$$QoS^i_{grade} = \frac{1}{4} * \sum_{n=1}^{4} QoSMetric^i_{grade} \tag{2}$$

$$QoE^i_{grade} = Normalize(QoE^i_{estim} * Path^i_{share}) \tag{3}$$

In equation (2) $QoSMetric^i_{grade}$ refer to grades computed for the following four QoS metrics: throughput, loss, delay and delay jitter, expressed in the 0-100 range [49]. In this work, these QoS metrics are considered with equal importance and therefore the grades have equal weight in the QoS^i_{grade} formula.

In equation (3) QoE^i_{grade} is computed by normalizing the contribution path i traffic share has on the overall user perceived quality estimation QoE^i_{estim}. The resulting value is also expressed in the 0-100 range. The traffic share $Path^i_{share}$ is computed from the current throughput on path i $Thru^i$ and overall thoughput $Thru = \sum Thru^i$, as shown in equation (4):

$$Path^i_{share} = \frac{Thru^i}{\sum Thru^i} \tag{4}$$

The estimation of user perceived quality is performed using equation (5) [50] and is expressed in terms of PSNR and measured in decibells. $Max\_BitRate$ is the maximum transmitted video bit rate, $TxRate$ is the current transmission rate, $Thru$ is the current throughput, and each is computed as a summation of individual contributions on all traffic carrying paths i.

$$QoE_{estim} = 20 \cdot \log_{10}\left(\frac{Max\_BitRate}{\sqrt{(TxRate - Thru)^2}}\right) \tag{5}$$

Based on packet timestamps and sequence numbers, the Quality Monitor measures the values of the four QoS parameters: throughput, loss, delay and delay jitter, and statistics are collected. Average values of these quality parameters are stored at the Quality Monitor and are reported periodically to the Rate Controller. After the report is delivered, all the

Algorithm 3 Quality Monitoring Algorithm.

Procedure:
$SetNextReportTime(NextReportTime)$;
for all i such that $1 \leq i \leq No\_Paths$ **do**
  for all $Msg = Receive\_Data\_Message(Path^i)$ **do**
    $Increment(Path^i, Message\_Count_i)$;
    $Update(Path^i, Thru_i); Update(Path^i, Loss_i)$;
    $Update(Path^i, Delay_i); Update(Path^i, Jitter_i)$;
    if $NextReportTime$ **then**
      $Send\_To\_Rate\_Controller$:
        $Report(i, Thru_i, Loss_i, Delay_i, Jitter_i)$;
      $Reset(Path^i, Message\_Count_i)$;
      $Reset(Path^i, Thru_i); Reset(Path^i, Loss_i)$;
      $Reset(Path^i, Delay_i); Reset(Path^i, Jitter_i)$;
    else
      $Save(Path^i, Last\_Seq_i, Msg.Seq)$;
      $Save(Path^i, Last\_Delay_i, Msg.Delay)$;
    end if
  end for
end for

counters and average values are reset and monitoring continues for another pre-defined time interval. Algorithm 3 presents the pseudo code for the **Quality Monitoring Algorithm**.

Rate Controller performs rate adaptation based on the feedback quality reports received from the Quality Monitor and QMS metrics are computed for each path. Algorithm 4 presents the pseudo-code for the Rate Adaptation Algorithm used during content delivery. Adaptive measures are taken each time QMS values (calculated for each path separately) experience a significant variation ($QualityVariation$). $QualityVariation$ is computed by additively combining the absolute values of the individual quality variations for all the paths. A $Threshold$ with a typical value of 10% is used when assessing the extent of quality variation in order to avoid to respond to natural minute fluctuations and cause a ping-pong effect.

The Rate Adaptation Algorithm aims at achieving an aggregated transmission rate of $TargetRate$ in order to meet the given multimedia application requirements. This is achieved by combining individual contributions of flows originating at different sources and using different paths to destination. The individual rate allocation for each path ($Rate_i$) is computed by the Rate Controller based on the set of values $QualityRate_i$, which normalise the QMS_i values. These QMS values are associated with each path i and are caculated using the Quality Monitor-reported QoS parameter values for $Path^i$.

The first step in the Rate Adaptation Algorithm consists of calculating the quality scores for each active source separately. The best sources are selected which have enough traffic capacity to deliver the multimedia content at the target bitrate in order to minimise the number of concurrent streams. This is beneficial for traffic distribution, path management and energy consumption. A guard is maintained in order to prevent overloading to occur.

In the second step, the rate share is computed for each

Algorithm 4 Rate Adaptation Algorithm.

Input:
$TargetRate$; $Loss_i$; $Delay_i$; $Jitter_i$; $Thru_i$; **Output:** $Rate_i$;$1 \leq i \leq No\_Paths$;
Procedure:
  $QualityVariation \Leftarrow 0$
  $i \Leftarrow 0$
  for all i such that $1 \leq i \leq No\_Paths$ **do**
    GetFeedback($Loss_i$, $Delay_i$, $Jitter_i$, $Thru_i$)
    Compute($QualityRate_i$);
    Update($QualityVariation$);
  end for
  if $QualityVariation > Threshold$ **then**
    SortAscending($QualityRate_i$);
    $TotalRatio \Leftarrow 0$;
    $i \Leftarrow 0$
    for all i such that $1 \leq i \leq No\_Paths$ **do**
      if $TotalRatio < 100$ **then**
        if $TotalRatio + QualityRate_i > 100$ **then**
          $Rate_i = TargetRate * (100 - TotalRatio)/100$;
          $TotalRatio = 100$;
        else
          $Rate_i = TargetRate * QualityRate_i/100$;
          $TotalRatio = TotalRatio + QualityRate_i$;
        end if
      else
        $Rate_i = MinRate$;
      end if
    end for
  end if

source according to both individual quality scores and application requirements. The quality scores are expressed on a 100 point scale and represent the estimated share (expressed as percentage) of the total delivery target rate that a certain path can transport at high quality.

The rate $Rate_i$ associated with a path i represents the amount of data from the total delivery rate which can be transported at high quality over path i. This rate is used by the Rate Adapter module to adapt each sub-stream rate accordingly.

The proposed cloud-based multimedia content delivery solution M3QD also supports mobility by employing the Smooth Adaptive Soft Handover Algorithm (SASHA), which gracefully transfers the traffic from old fading networks to new ones as they become available. SASHA is deployed at the **Rate Adapter** level and is described in details in [49].

IV. Performance Analysis

A. Simulation Environment, Models and Prototype

1) Simulation Setup: NS-2 Network Simulator (v2.29) [51] was used for modelling and simulations. The radio patch developed by Marco Fiore [52] was included in the NS-2 simulation testbed in order to offer support for more realistic wireless communication channels.

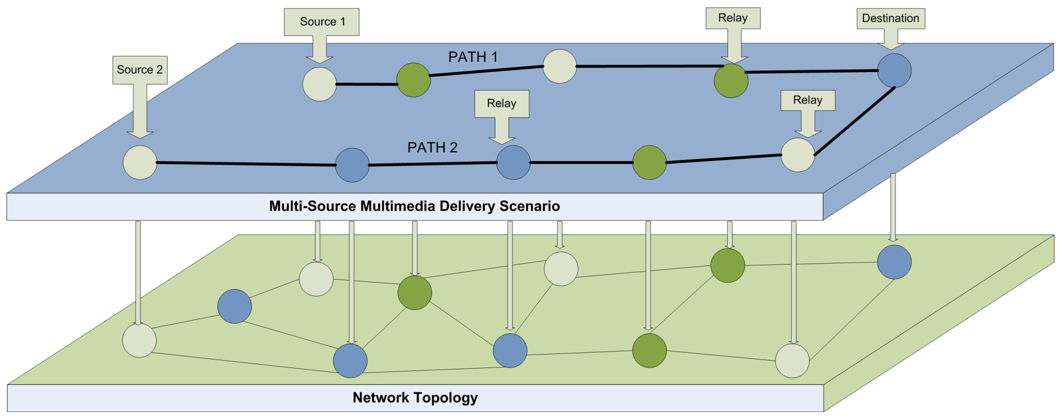

Fig. 5. Simulated network topology for the multi-source approach.

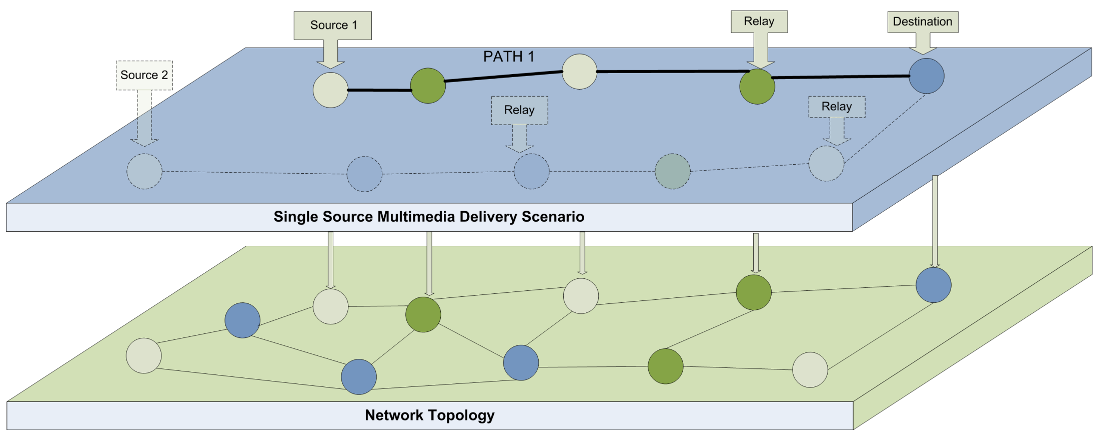

Fig. 6. Simulated network topology for the single-source approach.

The proposed cloud-based multi-source multimedia content delivery solution (M3QD) was modelled and deployed in NS-2 at application layer, as described in the previous section of this paper. A simulation model for single-source multimedia content delivery solution (SSMD) was also built in order to enable the performance comparison with the proposed multi-source-based scheme over the same network topology. SSMD is the classic approach used in general for delivering multimedia content from a single source. SSMD supports mobility at the level of ah-hoc routing when the current path becomes unavailable or by restarting the multimedia content delivery from a different source in case the current one becomes unreachable.

The simulated ad-hoc topology is presented in Fig. 5 and Fig. 6 for M3QD and SSMD approaches, respectively. When M3QD is employed, two content sources are used, each delivering multimedia content to the destination via a distinct path. When SSMD is employed, the two sources are still available; however only one content source at a time is used.

A summary of the network parameters used in the simulations is presented in Table I.

TABLE I
SIMULATION SETUP

Parameter	Value
Simulator	NS-2.29 [51]
Patch	Marco Fiore [52]
WiFi Protocol	802.11g
WiFi Mode	Ad-hoc
WiFi Tx Rate	6 Mbps
Queue	DropTail
Queue Size	50 packets
Traffic Type	MPEG2 Video Trace Files
Number of Clips	4
Clip Resolution	800x480
Clip Frame Rate	25fps

2) Emulator Prototype System: For video quality assessment a mobile cloud emulator prototype system has been developed. The emulator includes two components: one which deploys an adaptive Multiple Description Coding (MDC) scheme implemented in C++ and the other component which consists of the NS-2 enhanced with the M3QD and SSMD models. MDC has been introduced to support real-life multi-source video content delivery. The NS-2 models are used for simulating network delivery scenarios. The architecture of this prototype system is presented in Fig. 7.

The adaptive MDC scheme was implemented based on an MPEG encoder. It allows a video clip to be encoded in multiple descriptions (or streams) which can be independently sent over multiple paths. The encoding-delivery-decoding process works as follows. The original video clip is composed of frames. These frames are split into sub-frames by distributing each line of the main frame to a separate sub-frame in a round-

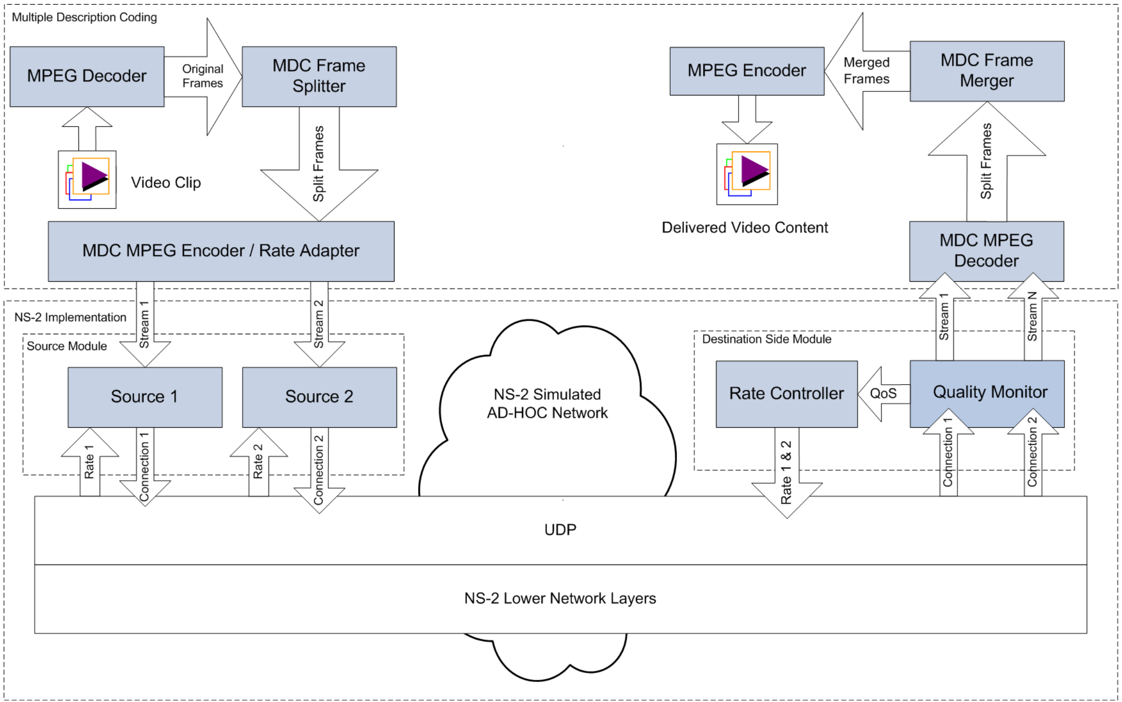

Fig. 7. Emulator prototype system

robin manner. The split frames are then separately fed into the MPEG encoder producing independent sub-streams (descriptions). Each stream is encoded at the bit-rate dictated by the M3QD Rate Controller according to the networking scenario considered in the 0.1 Mbps to 1.5 Mbps range. The video stream is packetised and according to the simulation results, the data corresponding to the received packets is copied in the sub-stream, while the data associated with lost packets is discarded, emulating the transmission effect. The delivered sub-streams are then decoded into independent frames which are then merged and re-encoded into the final content. Finally, the resulting clips are used for video quality assessment.

B. Testing Scenarios

Four distinct video clips were chosen (see Fig. 8) for video quality assessment. Each represents a movie trailer with a different amount of spatial and temporal motion content, as follows: low spatial-low temporal, high spatial-low temporal, low spatial-high temporal and high spatial-high temporal motion content. These clips were such chosen in order to cover a large range of video content and therefore be representative in terms of major spatial and temporal motion categories. The average length of each clip is 2 minutes. Clips are encoded using MPEG-2 standard and have a resolution of 800x480, and a frame-rate of 25fps, typical values for video content manipulated on portable devices. MPEG-2 was chosen due to its maturity and ease of access to open source encoders for the prototype development. However, the frame splitting used in the experiments is independent of the encoder used and consequently any standard encoder can be used with good performance, including MPEG4 or H.264, for example.

The proposed multimedia delivery solution targets portable devices, ranging from smartphones to notebooks. Consequently the clips' resolution of 800 x 480 has been such chosen to match a mid range graphical screen resolution for today's smartphones, tablets and notebooks.

Fig. 8. Frames from ”A-Team”, ”Nine”, ”Robin Hood” and ”Salt” trailer clips used for testing

Two distinct scenarios are considered. In each scenario background traffic is generated on the paths in order to create unbalanced load and consequently to trigger source handover. In the first scenario (**Scenario 1**) each path has a traffic node which generates video-like CBR background traffic of the pattern presented in Fig. 9. In the second scenario (**Scenario 2**) there are four traffic nodes for each path, the cumulative CBR traffic presenting the same pattern as in Fig. 9. Multiple nodes are used in the second scenario to determine higher collision probability.

Using the prototype system, each media clip was delivered a mobile device using M3QD and SSMD solutions, respectively.

TABLE II
OBJECTIVE VIDEO QUALITY ASSESSMENT RESULTS

Scenarios	PSNR (dB)	VQM	SSIM
M3QD Scenario 1	20.89	4.39	0.858
SSMD Scenario 1	15.35	8.76	0.691
M3QD Scenario 2	21.69	4.36	0.860
SSMD Scenario 2	18.38	3.59	0.882

TABLE III
OBJECTIVE VIDEO QUALITY ASSESSMENT - PEARSON CORRELATION

Scenarios	PSNR-SSIM	PSNR-VQM	VQM-SSIM
M3QD Scenario 1	0.75	0.85	0.93
SSMD Scenario 1	0.94	0.96	0.99
M3QD Scenario 2	0.82	0.89	0.94
SSMD Scenario 2	0.85	0.86	0.99

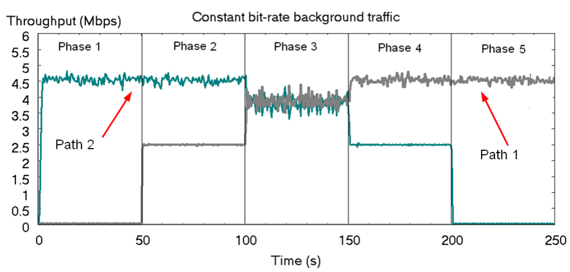

Fig. 9. Constant bit-rate background traffic.

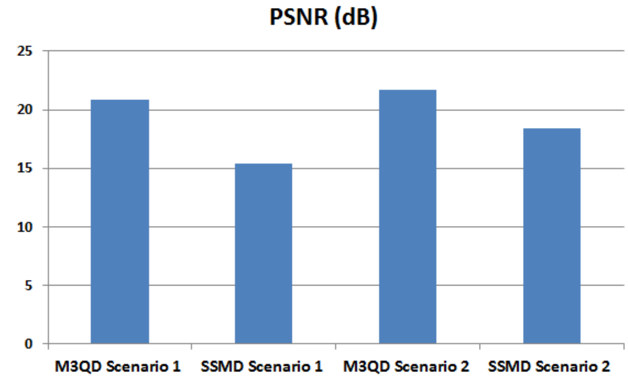

Fig. 10. Objective video quality assessment in terms of PSNR

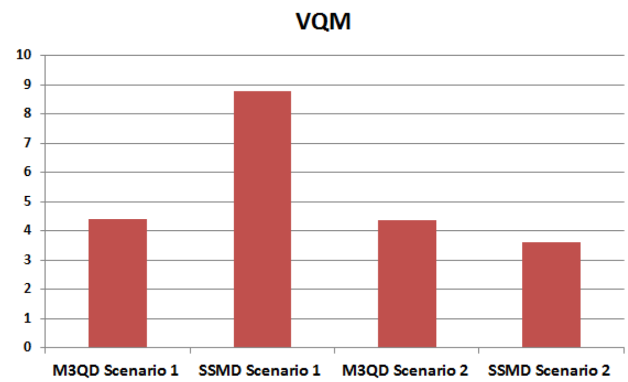

Fig. 11. Objective video quality assessment in terms of VQM

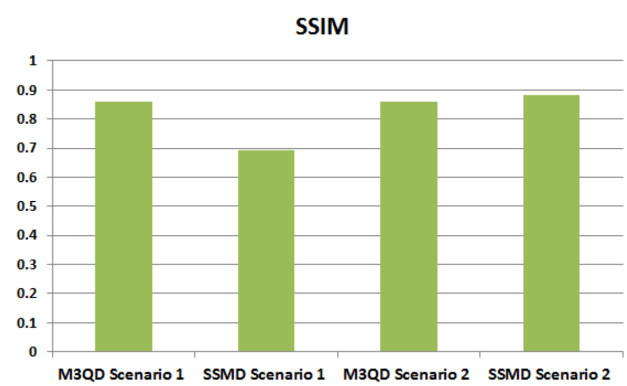

Fig. 12. Objective video quality assessment in terms of SSIM

C. Results Analysis

1) Objective Video Quality Assessment: Objective video quality assessment uses complex algorithms or models to evaluate the quality of the video content as close as possible to the way human visual system perceives it. There is no objective video quality metric generally accepted for measuring user perceived quality with high accuracy.

Consequently, in this paper three distinct full reference metrics have been used: Peak Signal-to-Noise Ratio (PSNR) [43], Video Quality Measurement (VQM) [45], and Structural Similarity (SSIM) [44]. The higher the scores obtained using PSNR and SSIM the better is the quality, while in case of VQM the lower the score - the higher the quality is.

Table II presents the results obtained when M3QD and SSMD solutions are used in turn in the two network scenarios considered. It can be observed in the table that in terms of PSNR, the multi-source-based approach performs better than the single source approach.

M3QD presents PSNR scores around 21 dB which is a good level for video transmissions over lossy wireless channels. SSMD presents poor PSNR scores with values as low as 18.38 dB and 15.35 dB.

In terms of VQM and SSIM metrics, M3QD presents similar scores in both scenarios demonstrating its resilience to different number of wireless nodes engaged in data traffic simultaneously. Although SSMD performs much worse than M3QD in the first scenario, in the second scenario its performance presents a slight improvement. This is consistent with the improvement noticed for the M3QD solution in the same conditions.

Fig. 10, Fig. 11 and Fig. 12 present comparative average PSNR, VQM and SSIM scores obtained by the two delivery approaches in the tested conditions. It can be seen clearly how M3QD outperforms SSMD in all situations, regardless of the video quality metric used in the assessment.

In particular in terms of PSNR M3QD has achieved on average a 26% improvement over SSMD, VQM shows a performance better with 29% and SSIM presents a 10% improvement when M3QD is employed instead of SSMD.

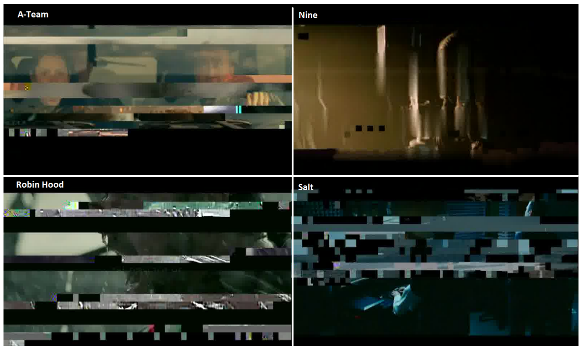

Fig. 13. Image distortion when using SSMD.

Fig. 14. Image distortion when using M3QD

Fig. 15. Subjective assessment - video quality

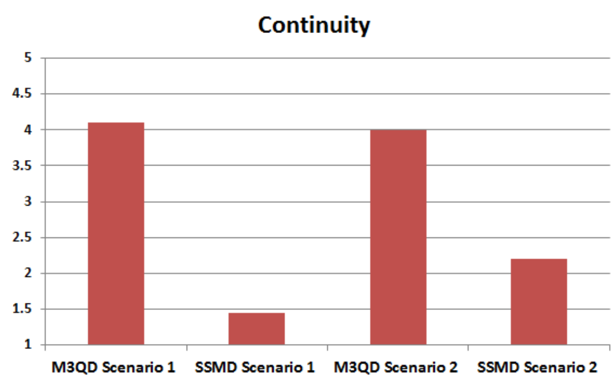

Fig. 16. Subjective assessment - video continuity

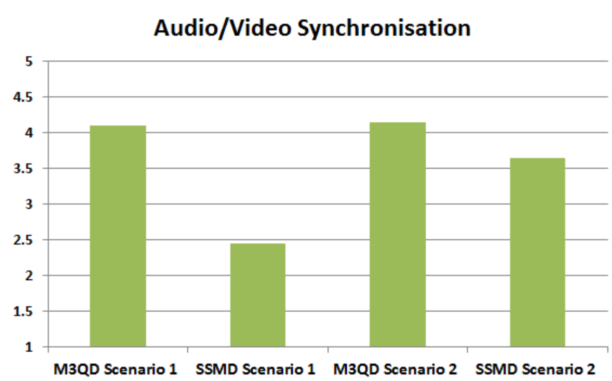

Fig. 17. Subjective assessment - audio-video synchronization

Considering the dispute regarding the accuracy of the existing video quality assessment metrics a Pearson correlation analysis has also been performed in order to verify the validity of the results and the consequent performance analysis.

Table III presents the correlation between the three objective video quality metrics employed in assessing the performance of M3QD and SSMD, respectively. It can be observed that VQM and SSIM present a very good correlation with a Pearson correlation coefficient higher than 0.9. PSNR results are also correlated with the other two; however the coefficients are more variable (between 0.75 and 0.96) depending on the scenarios used.

2) Subjective Testing: Subjective video quality assessment has been performed involving 22 human viewers.

The streamed multimedia clips are displayed on a average Notebook PC 13 inches monitor situated in a room with no natural light. The only source of light available was kept to a minimum intensity and did not disturb the participants. The viewing distance was set to 5 times the height of the picture.

The sample frames presented in Fig. 13 and Fig. 14 show the types of image distortions involved when M3QD and SSMD are used for content delivery. The users were asked to watch these clips and rate their perceived quality. Three distinct aspects are considered: overall perceived video quality, continuity of the video sequence and synchronisation between audio and video. ach of these aspects are rated on the five point ITU-T R. P.913 recommended scale, where 1 and 5 are the lowest and the highest levels, respectively. The results are expressed as average values and are shown separately for each network scenario in Table IV.

Fig. 15, Fig. 16 and Fig. 17 present the subjective video quality assessment results. These subjective testing results show a similar pattern with the objective video quality results presented in the previous section. It can be observed that on average the scores given by the test users to video deliveries using M3MD are better than those awarded for SSMD deliveries, with better playback continuity and very little loss of synchronization between the video sequence and the corresponding audio component. However, SSMD shows positive performance when four mobile nodes are used to generate background traffic.

TABLE IV
SUBJECTIVE VIDEO QUALITY ASSESSMENT RESULTS
(1 TO 5 SCALE)

Scenarios	Quality	Continuity	Audio-Video Sync.
M3QD Scenario 1	3.40	4.11	4.10
SSMD Scenario 1	1.65	1.45	2.45
M3QD Scenario 2	3.25	4.00	4.15
SSMD Scenario 2	2.95	2.20	3.65

Statistical analysis was performed on the results to evaluate if there is a significant statistical difference between video quality, video continuity and audio-video synchronization scores, respectively received by the two schemes in the two scenarios. To determine which scheme performs better and in which conditions, multiple two-sample t-tests were performed with 95% confidence level (α=0.05).

In terms of video quality, the statistical analysis shows that there is no significant difference between the performance of M3QD in the two scenarios considered (significance level p = 0.023). The single source approach shows a significant difference (p=0.031) between the two scenarios, with a better performance when the four background traffic nodes are involved. Regarding the comparison between the two different schemes, it can be stated clearly that M3QD performs better than SSMD in each of the two scenarios (p=0.028 and p=0.042).

A similar trend was observed when analysing the scores given by the users to playback continuity and synchronisation between the video and the audio content.

V. CONCLUSION

This paper has introduced a novel Mobile Multi-source High Quality Multimedia Delivery Scheme (M3QD) for multimedia content distribution to mobile users over hybrid ad-hoc and infrastructure-based wireless networks. The proposed solution is based on a suite of algorithms which support high quality content delivery while enabling user mobility. M3QD and its algorithms are evaluated using both simulations and subjective tests. M3QD's performance is compared with that of a single source multimedia delivery scheme in different scenarios when delivering various multimedia content clips. Testing results show how the proposed M3QD approach achieves up to 33% better video quality in terms of PSNR during objective simulation-based tests and up to 1.5 levels in terms of the mean opinion score (MOS) when subjective video quality assessment is performed.

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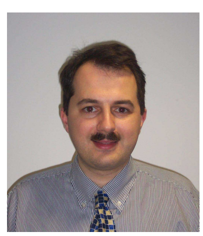

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