RESEARCH ARTICLE

Quality of Experience and Quality of Service-Aware Handover for Video Transmission in Heterogeneous Networks

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Summary
Heterogeneous networks offer a wide range of multimedia services, such as entertainment, advertising, and video conferences. In this multimedia scenario, users can access video content via heterogeneous wireless networks, such as LTE macro and small cells. Users also expect to receive real-time videos with Quality of Experience (QoE) support, which is a challenging task due to the great diversity of radio base stations in such heterogeneous environments. In this article, we introduce a Quality of Service (QoS-)/QoE- and Radio-aware (SER) handover management algorithm for heterogeneous networks to provide video dissemination with QoS/QoE support. SER algorithm considers the Analytic Hierarchy Process (AHP) to adjust the degree of importance of each criterion in order to select the appropriate radio base station that the mobile node must connect, allowing efficient handover decision-making for video transmission with high user experience. Simulation results show that the SER algorithm delivered videos with significant improvement on QoE than existing handover algorithms.

KEYWORDS
Handover, HetNet, QoE, QoS, Video, H264

1 | INTRODUCTION

According to Cisco forecasts [1], in 2017, the amount of video transmitted over wireless networks accounted for about 75% of all Internet traffic, and it is expected to exceed 82% by 2022. This growth is because users produce, share, and consume real-time video services connected to wireless network infrastructure (*e.g.*, the cellular network) while walking, driving in their vehicles, or taking public transport [2]. However, current cellular networks, such as LTE, are not enough to provide satisfactory services to existing mobile multimedia applications [3]. The actual use of the Heterogeneous Networks (HetNets), is considered as the best approach to meet the current network requirements [4].

HetNets are composed of macrocells and small cells, such as proposed by 3GPP LTE-Advanced standardization [5,6]. HetNets are widely deployed in urban environments, increasing the transmission capacity in a large coverage area [7]. The small cells (*e.g.*, femtocell, picocell) have different radio range and network characteristics to increase the transmission rate, while decrease traffic on the macrocells [8]. In these HetNets environment, the handover decisions should be carefully executed to ensure the requirements of video applications, such as low packet loss and delay, as well as QoE support [9]. For instance, a user moving in a vehicle can travel across different geographical areas in a short time interval, forcing it to perform frequent handovers to maintain connectivity with the video service provider [10]. In this way, the handover must occur without reducing the QoE, *i.e.*, a video without ghost effects, pixelization or screen freezing, regardless of the networks' conditions and characteristics or the user's mobility [11].

The handover process consists of three phases: measurement, decision, and execution. Specifically, the mobile device performs the handover discovery by scanning nearby networks. Based on the collected information from nearby networks, the infrastructure will decide and trigger the mobile to perform the handover, while the execution phase performs all procedures to transfer the connection between the mobile device and the new radio base station. All handover phases are performed by an entity called Handover Manager, such as the Mobility Management Entity of the 4G networks. In this sense, the Handover Manager is a key factor to support mobile multimedia application in HetNets [12]. Existing handover algorithms consider radio (*e.g.*, signal strength) or QoS as context parameters for handover decisions [13,14]. Signal strength is an important parameter for handover decisions, but considering it alone or together with QoS is not an efficient approach to provide a good handover decision for mobile multimedia applications [3]. Also, QoS schemes alone are not enough to assess, control, and improve the quality level of multimedia applications based on user experience [15]. In heterogeneous networks, subjective aspects of video content concerning the user's perception and satisfaction should be considered to perform handovers [10].

In this way, QoE must be measured and integrated for decision-making to improve the handover decision, while assuring the video service requirements for mobile users. However, current wireless networks have not been designed considering QoE principles, and thus current HetNets must shift from QoS-centric to QoE-centric approaches [11]. The QoE-aware approach brings many benefits not only to the user but also to mobile operators involved in providing video services [11], as seen in recent studies about video distribution that argue that if a consumer is unsatisfied with the performance of video application (*i.e.*, QoE), he/she might change the mobile operator [16]. This consumers' evasion can be avoided with a handover algorithm that takes into account multiple metrics for handover decision in order to provide video dissemination with QoE provisioning.

An efficient handover algorithm can be modeled as a multiple-criteria decision-making (MCDM) [17], since a multimedia-aware handover scheme must take in account radio, QoS and QoE parameters to allow the user to be always best connected. However, the degree of importance for each metric changes continuously at runtime, and it has a significant influence on the handover decision. In this context, the Analytic Hierarchy Process (AHP) theory [18] is an essential MCDM solution, which decomposes a complex problem into a hierarchy of simpler subproblems. AHP combines qualitative and quantitative factors for the analysis, allowing the system to find an ideal solution when several metrics are considered in the handover process.

In this article, we introduce the SER (Service, Experience, and Radio) handover algorithm, which is an MCDM algorithm to deliver video content over HetNets with QoS/QoE support. The SER algorithm considers Reference Signal Received Quality (RSRQ) as a radio parameter, Package Delivery Ratio (PDR) as a QoS criterion, and hybrid QoE estimation (*i.e.*, Predictive Mean Opinion Score - pMOS) as the QoE parameter. SER algorithm also takes into account AHP to assign different degrees of importance for each criterion (RSRQ, PDR, and pMOS) according to network conditions, and also to calculate the quality for each cell during the handover decision in order to select the appropriate network that the mobile node must connect. We performed simulations to evaluate the performance of SER algorithm to disseminate videos in HetNets in comparison to existing handover algorithms. Based on simulation results, the SER algorithm delivered videos with 12% better QoE than analyzed algorithms. The main contributions of this article are summarized as follows: (i) introduce an MCDM-related handover management algorithm that takes into account three different criteria, which have a positive impact on the handover decision to improve the user experience for mobile multimedia applications. (ii) Use distinct analysis (*i.e.*, video characteristics, user preferences) to determine the best handover management algorithm for video distribution in the heterogeneous scenario. (iii) Use simulations to show the performance of SER for video distribution in HetNet scenarios compared to existing handover algorithms.

The remainder of this article is organized as follows. Section 2 introduces the related work about handover algorithms, their main drawbacks to provide video dissemination with QoS/QoE support in HetNet scenarios. Section 3 presents the main characteristics of the SER algorithm. Section 4 gives details about the simulation methodology and introduces the simulation results to evaluate the performance of SER for video distribution compared to existing handover algorithms. Finally, Section 5 presents the concluding remarks.

2 | RELATED WORK

Research on efficient handover algorithms in HetNet is essential to provide high performance in delivering video content to mobile users. However, designing such algorithms is not a simple task due to the networks' diversity and the requirements of the video services, such as low packet loss and delay. Over the past few decades, several handover algorithms were proposed, such as Media Independent Handover (MIH) [19]. MIH was proposed to standardize the different technologies related to IEEE 802.21 standard under one interface. However, the heterogeneity increased, and it is still a significant and recurrent challenge. Besides, the handover process needs to take into account the consumer/user needs. Hence, handover algorithms underwent a process of evolution, considering different parameters and techniques.

Handover algorithms purely based on signal strength (*e.g.*, RSSI-based and strength-based) were initially designed and implemented on a large scale basis. These algorithms consider the Received Signal Strength (RSS) from the available cells in order to perform the handover to the cell with the highest signal strength value [13]. In current and future HetNet scenario, the deployment of small cells along with macrocells can be a better alternative in economic terms (cheaper costs) and to fulfill QoS requirements (improving coverage) [20]. However, handover algorithms purely based on signal strength are not appropriate to current HetNet demands.

In the past few decades, multimedia services aimed to provide network-centric handover decision, due to increasing heterogeneity and consequently network complexity [17]. Specifically, a QoS-aware algorithm for handover decision takes into account parameters related to network services, such as channel bandwidth, throughput, delay, and jitter [21,14]. Traditional Power Budget Algorithm (PBGT) [14] activates the handover execution when it detects a higher signal value in neighboring cells compared to the original cell. As a QoS requirement, this handover executes after taking into consideration both hysteresis (handover margin with value in dB that the handover only executes if the target cell presents better signal strength than the serving cell plus this handover margin) and time-to-trigger (when an algorithm awaits a particular time to perform handover) [22], that are used to tackle unnecessary handover issues. Chaudhuri et al. [23] introduced an extension of PBGT for LTE-A by controlling time-to-trigger and hysteresis for handover decision [14]. Although QoS-aware handovers have better performance at a HetNet scenario, it is not appropriate for multimedia applications due to poor performance [24].

Xenakis et al. [25] give details about the benefits and challenges of using small cells in HetNet, highlighting the importance of considering smaller cells in the load balancing of network infrastructure. However, it does not consider video content application. Zhang et al. [26] separate applications into user experience sensitive or insensitive ones. This differentiation is to try to prioritize distinct applications to meet user satisfaction. However, this work uses only highly sensitive applications (video content), and a distinction between the videos is not appropriate.

Even though a handover can increase the QoS, it does not directly relate to QoE [27], so there is a need to check this aspect for the handover carefully. Liotou et al. [11] propose a QoE management architecture in mobile cellular networks to provide a more user-centric approach. This change from network-centric to user-centric can be useful for video streaming applications because it captures subjective aspects from multimedia content. However, the use of QoE-only parameters sometimes does not meet the requirements of the HetNet scenarios, where the handover management can work with multiple parameters to handle the multi-tier scenario.

In a multi-tier scenario of distinct base station cells, it is appropriate to consider multi-parameters to have the best decision. MCDM techniques can be categorized as this type of algorithm, as defined by Ahmed et al. [17]. MCDM-based handover mechanisms can make reasonable handover decisions [28], because it can acquire relevant information from the environment and make decisions. Chinnappan et al. [29] use the weights of an AHP in a WiMAX environment. The AHP technique shows that its use provides a low complexity resolution and presents a good response. Drissi et al. [21] also use AHP for a multi-criteria handover, with only QoS parameters. Finally, Hussein et al. [30] evaluate and solve an MCDM by applying fuzzy TOPSIS, considering criteria more focused on radio aspects. *e.g.*, signal strength and uplink signal-to-interference-plus-noise ratio. However, none focus on a highly sensitive application in this scenario.

Based on our analysis of the state-of-the-art, we conclude that it is fundamental to consider different parameters for handover decision in a HetNet environment. Furthermore, handover algorithms must be based on MCDM, due to the diversity of the parameters to be considered [31]. In this sense, we consider that a radio-, QoS-, and QoE-aware handover algorithm in a HetNet environment provides QoS/QoE support for the mobile multimedia application. However, to the best of our knowledge, all of these key features have not been provided in a unified handover algorithm yet. Finally, Table 1 summarizes the main characteristics of previous works intended to provide handover decisions.

3 | SERVICE, EXPERIENCE, AND RADIO HANDOVER ALGORITHM

This section details the SER algorithm, which takes into account QoS, QoE and radio parameters for handover decision for mobile multimedia applications. In the handover measurement phase, SER collects RSRQ, PDR, and pMOS. In handover decision, SER considers AHP to adjust the degree of importance of each parameter, allowing a more efficient handover decision. Finally, the handover execution phase is responsible for the handover accomplishment. In this way, the SER algorithm delivers videos with QoS/QoE support to mobile users connected to HetNets.

3.1 | SER Overview

Figure 1 presents an overview of SER algorithm at three-time instants (*i.e.*, t_1, t_2, and t_3), depicting three distinct cells and a mobile node at a linear sequence of events, from t_1 up to t_3. In this scenario, we represent only one mobile node (*i.e.*, vehicle) consuming a particular video service, while moving from left to right. The mobile node may be connected to different cells (*e.g.*, macrocell A or C or small cell B) at each time interval. In such a scenario, there are other nodes connected to each cell, which are not represented to facilitate the understanding of the handover algorithm. The tables at the bottom of each time interval introduce values of RSRQ, PDR, pMOS, and cell quality for each available cell for the mobile node in the scenario. The cell with blue circle represents the serving cell, while the green circle represents the cell that the mobile node must perform handover based on the handover decision phase (*i.e.*, the target cell). The less adequate cells are depicted with a red circle (*i.e.*, the candidate cell). The lower tables are also depicted as colors: blue color for the serving cell, green color for the target cell, and the candidate cells are shown as white color to provide a more readable and understandable figure.

The SER algorithm considers the RSRQ ∈ [-19.5, -3], PDR ∈ [0,1], and pMOS ∈ [1,5] as input parameters to AHP, that processes such information to produce a weighted value called AHP score ∈ [0,1] for each cell. Each one of these parameters and the AHP score attest that the higher their values indicate as better quality for the consumer. RSRQ is collected by the node, while pMOS and PDR are collected by the radio base stations of each cell. Each table presents the current information of RSRQ, PDR, and pMOS at the three distinct time intervals. In the left table, at the time interval t_1, macrocell A displays an RSRQ of -7, average pMOS of 4 and average PDR of 0.7, resulting in an AHP score of 0.4. The small cell B and macrocell C both have lower AHP scores at the same time instant (0.28 and 0.32, respectively). The algorithm calculated all the AHP scores for each time instant based on the collected info from the tables.

In Figure 1, at the time interval t_1, the mobile node is consuming a video connected to macrocell A, which has better conditions regarding RSRQ, pMOS, and PDR compared to cells B and C and the handover decision was to maintain the mobile node at its serving cell (macrocell A). On the other hand, at time interval t_2, the mobile node moved while keeping connected to cell A, but the RSRQ, PDR, and pMOS values for the available cells changed (due to the presence of the other consuming nodes, which are not depicted to facilitate the understanding of the figure). Therefore, the SER algorithm computed the quality of each cell, and the cell B is considered as a target cell since it has better conditions to provide a reliable connection to the mobile node. The algorithm executes the handover from macrocell A to small cell B at the transition from the time interval t_2 to t_3. In time interval t_3, the small cell B, which is now the serving cell, continues to present the best status, confirming and reassuring the good decision made by the handover algorithm.

3.2 | Handover Algorithm

We consider that all handover phases are performed by an entity called Handover Manager, such as the Mobility Management Entity of the 4G networks. The Handover Manager has a connection to each cell, such as the S1 interface of the 4G networks. Algorithm 1 introduces the main operations performed by the SER algorithm to deliver video content with QoE support for mobile multimedia applications. The Handover Manager executes all three phases, while the mobile node is connected to any cell (Lines 1-5). At the measurement phase, the Handover Manager must obtain information required for handover decision, such as RSRQ, PDR, and pMOS (Line 6). The handover decision phase is responsible for selecting the best cell that the mobile node must connect by using the AHP, and considering the information collected in the previous phase (Lines 7-11). Finally, the handover execution phase is responsible for changing the connection between the mobile from a serving cell to a target cell, chosen by Handover Manager (Lines 12-14). In the following Sections, we introduce more details about each phase.

Algorithm 1: SER algorithm

Input: Cell and mobile node information

Output: Handover Decision and possible Execution

∀ mobile nodes and ∀ radio base stations
radio base station managed by Handover Manager
mobile node connects to closest radio base station
mobile node requests video content
while *mobile node is connected* **do**
    Handover Manager initiates the information measurement phase by requesting RSRQ measurements of the mobile nodes as well as average PDR and pMOS information from the radio base stations
    Handover Manager initiates the decision phase
    for *each available cell* **do**
        Calculates the AHP score
    end
    BestCellId = cell with highest AHP score
    if $BestCellId \neq ServingCellId$ ***and*** $BestCellRSRQ \geq Threshold$ **then**
        initiates the handover execution phase
    end
end

3.2.1 | Measurement Phase

At the measurement phase, the SER algorithm requires to collect information from both mobile device and radio base station side. We consider the information from existing connections between mobile nodes and radio base station in order to understand the performance of the radio base station, and thus takes the best decision. Specifically, from the serving and candidates cells, the SER algorithm collects the QoS and QoE, enabling to understand the quality of such a connection.

If the radio base station is idle, the Handover Manager assigns the maximum QoS and QoE values since there is no mobile node connected to it. This strategy is used for Handover Manager to give preference to idle radio base stations, adjusting the load balancing on all available radio base station. Concerning radio parameters, the mobile nodes periodically send the experienced RSRQ value from the current serving cell and candidate cells to the Handover Manager. In this way, the Handover Manager collects to the radio, QoS and QoE information for all available radio base stations for a given mobile node, and thus starts the handover decision phase.

Regarding QoS parameters, SER algorithm takes into account PDR in order to evaluate the connection between the radio base station and the mobile node, in terms of the ratio between packets that are successfully delivered to a destination compared to the number of packets that have been sent by the source. In this way, SER could evaluate the packet loss of the radio base station. From the radio perspective, the SER algorithm considers the RSRQ value experienced by the mobile node for each beacon message transmitted by the radio base station. RSRQ measures the received signal quality in the LTE networks.

Concerning QoE parameters, SER algorithm considers a QoE-monitor to compute at runtime and low complexity the QoE of a given video since a QoE-aware handover decision assists in the selection of a radio base station that delivers videos with better quality from the user perspective. Specifically, the SER algorithm takes into account a hybrid

QoE metric called pMOS computed by the radio base station for each transmitted video. Hybrid QoE video quality assessment measures the video quality level in real-time by taking into account the benefits of both objective and subjective QoE estimation methods. Hybrid schemes predict the QoE based on information of IP and video codec packet headers, where a machine learning technique predicts a human MOS score based on frame loss and video characteristics.

The QoE-monitor operates by calculating the frame loss ratio of each video. Specifically, a compressed video is composed of three types of frames, *i.e.*, I-, P- and B-frames [15]. These frames are arranged into sequences, called Group of Pictures (GoP), which contains all the information required to decode a given video within a period of time. Each frame has different priorities, where the loss of priority frames (*i.e.*, I-frame) can cause more severe video distortions than low priority frames based on the user perspective [10]. For instance, in case of an I-frame loss, all the subsequent P- and B-frames in the same GoP must be discarded since they depend on the I-frame to be reconstructed at the decoder. On the other hand, in case of a P-frame loss, the subsequent B-frames in the same GoP should also be dropped, until it reaches a P-Frame again. Finally, the loss of a B-frame only affects itself. Besides, the GoP size is also an important parameter, due to the distortion caused by an I-Frame loss will be more noticeable by the end-user in a video with longer GoP size than with a shorter one [32], because it also takes longer for the arrival of a new I-Frame that will fix the error. Therefore, the loss ratio of each frame and GoP size differently affects the QoE of transmitted videos.

Figure 2 shows an overview of the original software construction of the QoE-monitor steps, which considered an entire learning process, *i.e.*, training, testing, and validation. Initially, it requires a video source database composed of videos with different characteristics regarding GoP size and motion/complexity levels, as seen in Figure 2(a). Afterward, we transmitted these videos in a wireless network (with different numbers of users, congestion levels and technologies), getting information about frame loss ratio for I-, P-, and B-frames, and maintaining a distorted video database with all received flows, as depicted in Figure 2(b). Next, to create the database for the QoE score, volunteers watched these videos with different frame loss rates, as can be observed in Figure 2(c), and assigned a MOS value ranging from 1 to 5 for each video. This subjective video evaluation followed the recommendations from ITU-R [33,34]. GoP, frame loss ratio for I-, P-, and B-frames, and the assigned MOS values performed by the volunteers are stored, as seen in Figure 2(d).

Finally, pMOS uses Random Forest [35] as a low complexity machine learning technique to correlate the loss rate of I-, P-, and B-frames with the assigned MOS values given, achieving a final MOS score, as depicted in Figure 2(e), and thus concluding the construction of the pMOS technique. Random Forest works with the concept of forming smaller selections of a tree, informing different results in these smaller trees, and counting the most chosen solution (*i.e.*, majority tree) as the answer to a question, which is: the estimated MOS value considering GoP and loss ratio of I-, P-, and B-frames. Random Forest was selected because it is a very efficient general-purpose classification method [36]. It does not perform pruning (in contrast to single decision trees), and the search is faster [37]. It is important to notice that when we use the pMOS, it does not need to perform a full retrain of the technique again. The final pMOS technique can perform even with video flows not presented in the video database, since it is composed of videos with different motion and complexity levels.

In this context, the radio base station collects video-related information to compute the predicted MOS value by using deep packet inspection schemes. Specifically, each flow starts with a sequence header, followed by a GoP header, and then by one or more coded frames, and each IP packet contains one or more video frames. The deep packet inspector examines the MPEG bitstream and can verify which frame is lost in a GoP, without decoding the video payload. The packet inspector also collects information about the frame type and GoP size.

3.2.2 | Decision Phase

In the Handover Decision phase, the Handover Manager is responsible for selecting the best candidate radio base station for the mobile node to connect. The Handover Decision considers the RSRQ, pMOS, and PDR values collected in the previous phase. The SER algorithm uses AHP to estimate the best response according to the importance of each parameter to another [18]. AHP provides a structured technique for the decision making of problems with multiple criteria involved. It considers the pairwise comparison between the numerical values of each parameter and their relative degrees of importance, in order to adjust their weights at runtime. As a result, more essential metrics receive a higher weight. We define five importance levels for the comparison between each pair of parameters, as shown in Table 2.

The Handover Manager constructs for each mobile node its own matrix to compare all the pairs of criteria. We denote $C_{i,j}$ as the comparison matrix, as shown in Eq. 1. The comparison matrix $C_{i,j}$ represents how important is a criterion i compared to another criterion j. In this matrix, PDR is 2 times more important than the pMOS, then the inverse ratio (*i.e.*, pMOS concerning PDR) is 2 times less important. Based on simulation results, PDR is considered most important because its greater weight led the Handover Manager to choose the radio base station that delivers video with better quality.

$$
\begin{array}{r c}
 & \begin{array}{ccc} PDR & pMOS & RSRQ \end{array} \\
\begin{array}{r} PDR \\ C_{i,j} = pMOS \\ RSRQ \end{array} & \begin{pmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{pmatrix}
\end{array} \tag{1}
$$

The matrix $C_{i,j}$ is then normalized column by column by dividing each element by the sum of its column. In order to obtain the appropriate weight for each criterion, the eigenvector of the normalized matrix is used. In other words, for the relative importance of each criteria in Table 2 we obtain the eigenvector $W = [0.54, 0.30, 0.16]$, meaning that in the calculation of the AHP score, PDR will have the weight 0.54, 0.30 for the pMOS, and 0.16 for RSRQ. If the current radio base station has a PDR of 1, while the PDR of the candidate radio base station A is 0.7, then the current radio base station has greater weight in this criterion. In the end, AHP performs a dot product between the eigenvector and a vector that stores the measured values for each mobile node, obtaining the AHP score. Those that have the highest quality calculated is chosen as the cell with the best conditions to provide a reliable connection to the mobile node. It is important to highlight that Eq. 1 always presents this value since it was thus defined during the network judgment (when the most relevant criteria for the good performance of the algorithm are elected).

3.2.3 | Execution Phase

The Handover Execution Phase can be summed up in two distinct actions for the Handover Manager: perform handover or maintain the mobile user connected to the current radio base station. Specifically, there is no need to perform handover, as soon as the quality of the current radio base station computed by the handover decision is the highest than the all candidate radio base stations. However, the handover must be performed from the serving radio base station to the best available one, *i.e.*, target radio base station, as soon as the handover decision detected this situation. The handover execution only occurs if the measured RSRQ is above a predetermined threshold, which avoids unnecessary handover.

In the handover execution phase, the Handover Manager informs its decision to the serving and target radio base stations, detailing about which mobile node will be transferred. Control messages are transferred between radio base stations, such as the information about the node itself. The handover is then performed, in which it changes the communication path of the mobile node between the serving radio base station to the target radio base station.

4 | EVALUATION METHODOLOGY

This section describes the evaluation methodology, including scenario description, simulation parameters, metrics used to evaluate the QoE of delivered videos transmitted, and handover algorithms.

4.1 | Scenario Description and Methodology

We implemented the evaluated protocols in the NS-3.27*, and conducted 33 simulations with different randomly generated seeds by its default pseudo-random number generator (MRG32k3a) [38]. It is used to provide independent streams of random variables, for each probabilistic model†. For instance, it is used in Nakagami propagation loss model, LTE cells allocation in the proposed scenario, and background traffic of the LTE cells. Results show the values with a confidence interval of 95%. NS-3 implements the LTE protocol stack for communication between the mobile user with the radio base station. We consider simulation parameters presented by Tartarini et al. [8]. In this scenario, nodes move in a single highway at a 2D rectangular area of 3 km^2 (3000m X 1000m). For the simulation of traffic and vehicle mobility, we employed the Simulation of Urban Mobility (SUMO)‡, which is an open source traffic simulator to model and to manipulate objects in the road scenario. SUMO allows us to reproduce the desired vehicle movements with random speed based on empirical data. We consider a scenario composed by different kind of mobile nodes, which are moving at different speeds: $i)$ 30 nodes are moving with speeds between 0-10 km/h (*i.e.*, pedestrians); $ii)$ 30 nodes are moving with speeds between 11-75 km/h (*i.e.*, vehicles); $iii)$ 30 nodes are moving with speeds between 76-145 km/h (*i.e.*, trains). For the LTE infrastructure, we randomly distributed macrocells and small cells in the simulation scenario. To each radio base station in the scenario, background traffic taking up to 55% of the cell's bandwidth is randomly assigned.

The simulations consisted of transmission of video sequences with different motions and complexity levels, *i.e.*, Football, Mobile, and Highway, available from a well-known Internet repository§. We consider videos with different characteristics for our evaluation since small differences in motion and complexity level can influence the obtained QoE values [32]. In this way, it is important to perform the experiments with different video characteristics. These videos mainly have a duration of 10 seconds (except Highway with 20 seconds) and 300 frames each (except Highway with 600 frames), encoded with an H.264 codec ranging from 210 kbps (Highway) up to 576 kbps (Football), 30 fps and intermediate size (352 x 288 pixels). It should be noted that all the videos evaluated are streamed in a loop. The decoder uses a Frame-Copy method as error concealment, replacing each lost frame with the last received one to reduce frame loss and to maintain video quality. The main simulation parameters can be seen in Table 3.

We conducted simulations with four different handover algorithm to analyze their impact to deliver videos with good quality level. First, we consider **RSSI-Based** handover algorithm, which is the most common and traditional handover algorithm. It considers only the signal strength for handover decision, where a handover occurs as soon as there is a radio base station with higher signal strength value than the current one, as referenced by 3GPP [13] and Chang et al. [39]. Afterward, we consider **PBGT** [14,22] as handover algorithm, which considers RSSI, hysteresis, and time-to-

* http://www.nsnam.org/

† https://www.nsnam.org/docs/manual/html/random-variables.html

‡ http://sumo.dlr.de

§ http://media.xiph.org/video/derf/

trigger for handover decision. Third, we consider a **QoE-Based** handover algorithm, which mainly considers hybrid MOS techniques, such as the pMOS, for handover decision, as referenced by Liotou et al. [11]. Finally, we use **SER** as handover algorithm, which considers QoS, QoE, and Radio parameters for handover decision with the use of AHP technique, such as introduced in Section 3.

Regarding video quality assessment, QoS metrics alone are not enough to assess the quality level of multimedia applications, because they fail to capture subjective aspects of video content related to the human experience [11,32]. In this way, QoE metrics overcome these limitations. Thus we consider the well-known objective QoE metrics to evaluate the QoE of delivered videos, namely Structural SIMilarity (SSIM) and Video Quality Metric (VQM). SSIM $\in$ [0,1] evaluates the video frame-by-frame by comparing the following components: luminance, contrast, and structural similarity. The higher SSIM value means a video with better QoE. On the other hand, VQM $\in$ [0,4] evaluates perceived video damage based on characteristics of the human visual system, including blurring, noise, and color distortion. VQM values close to 0 stands for a video with better QoE. The Video Quality Measurement Tool (VQMT) was used to measure the SSIM and VQM values of each transmitted video.

Concerning QoS evaluation, PDR is a good estimation of the network aspects between the radio base station and mobile user connection. We must evaluate the handover effectiveness since every handover is a costly process for the infrastructure point-of-view. In this way, handover should be carefully executed by the Handover Manager to avoid wasting limited resources. In this sense, we consider two metrics to evaluate the unnecessary handover decision. The number of handovers is vital to give details about the average times that a specific handover management algorithm orders a single mobile user to change its radio base station. In addition, ping-pong is an important metric to evaluate unnecessary handover, since a ping-pong happens when the Handover Manager triggers the mobile device to perform a handover to a radio base station, but a few moments later (4-6 seconds) the mobile device returns to the previously connected radio base station (performing a second handover).

4.2 | Simulation Results

Figure 3 shows the SSIM values, in a bar chart representation, for videos with different motion and complexity levels, *i.e.*, Football, Mobile, and Highway, transmitted by SER, RSSI-based, PBGT, and QoE-based handover algorithms. By analyzing the results of Figure 3, we concluded that the SER algorithm delivers the Football video sequence with better SSIM (*i.e.*, an average of 7% better results) than other handover algorithms. The same can be observed when SER algorithm distributes Mobile video (*i.e.*, an average of 35% better results) and Highway video (*i.e.*, an average of 6% better results). It is important to mention that Mobile video is the most challenging video to transmit, due to its high motion characteristics. In this way, Mobile is a video heavily affected by the loss of a single frame. The overall SSIM improvement of SER handover can be explained by the fact that the SER algorithm combines QoS, QoE, and radio parameters for handover decision. We can see that these parameters have a more significant impact on the selection of efficient and reliable radio base station. Based on simulation results, the SER algorithm delivered videos with more than 12% better QoE than other algorithms.

Figure 4 shows the VQM values, in a bar chart representation, for videos with different motion and complexity levels, *i.e.*, Football, Mobile, and Highway, transmitted by SER, RSSI-based, PBGT, and QoE-based handover algorithms. In contrast to SSIM values, lower VQM values mean higher video quality level. The VQM results confirm the benefits of SER algorithm to deliver videos with better QoE support than RSSI-based, PBGT, and QoE-based handover algorithms. SER distributes Mobile video with the same quality as the other algorithms, but it delivers Football video with 11% less distortion and Highway video with 12% less distortion. SSIM and VQM results confirm that the SER algorithm can obtain better performance and it is the best suited at the distinct video transmissions.

Figure 5 shows the PDR values for videos delivered by SER, RSSI-based, PBGT, and QoE-based handover algorithms. By analyzing the results of Figure 5 we conclude that SER algorithm achieved the best values regarding packet delivered through the system. For instance, SER has a better PDR than the other algorithms from 22-26% (based on the average comparison) for all the evaluated videos transmitted.

Table 4 introduces the results of handover effectiveness, *i.e.*, number of handover and ping-pong, for the evaluated algorithms, which are directly related to the algorithm behavior. By analyzing the number of handovers in Table 4, we can see that RSSI-based algorithm executed around 44.95 handovers since the algorithm performs the handover every time the mobile node finds a candidate radio base station with higher RSSI than the current one, which can also cause the ping-pong effect. The ping-pong effect that RSSI-based algorithm presented (*i.e.*, around 50% of all total handover executions) also increases the overhead for the infrastructure. On the other hand, the SER algorithm executed an average of 4.73 handovers when delivering the video for a mobile node, and almost none occurrence of the ping-pong effect, which is a great achievement. Finally, PBGT and QoE-based algorithms performed around 1 handover each, and thus mobile node stayed connected almost entirely on the same radio base station, which is also an undesired situation because handover is essential for the mobile node to achieve better quality.

Figure 6 displays SSIM of each frame that composes the Highway video sequence transmitted by the four handover algorithms. When analyzing the results, it can be observed that SER starts connected to a good radio base station, while the other algorithms started with a bad connection (*i.e.*, SSIM below 0.8 [32,40]). As seen in the results of Table 4, SER performs an average of 4 handovers during the transmission of this video, *i.e.*, around frames 10, 87, 341, and 432. However, as the handover is usually performed during GoP transmission and due to I-P-B hierarchy, the quality is not instantaneous, being clearer perceived in the next GoP (if I-frame is lost), or the next B-frame (if B-frame is lost) or the next single frame (if P-frame is lost). Therefore, in this case, the video improvement has a delayed effect, *i.e.*, around frames 28, 114, 360, and 448. The better performance of SER handover can be explained by the fact that the QoE of delivered video reduced, and the Handover Manager decided to perform a handover to increase the QoE, confirming the good decision and execution of the handover. The other handover algorithms delivered nearly the entire video with poor SSIM performance, due to the mobile node is connected to a radio base station that cannot deliver the video frames with a good QoE. These SSIM results confirm that QoE is greatly affected by handover algorithms and how algorithms measure, decide, and execute the handover process.

Finally, we selected three random frames of the three different videos (*i.e.*, Frame #180 from Football, Frame #120 from Mobile, Frame #481 from Highway) in order to show the impact of handover decision executed by each algorithm from the user perspective, as shown in Figure 7. Figures 7(a) to 7(o) shows the original frame from Football, Mobile, and Highway videos and delivered ones by SER, RSSI-based, PBGT, and QoE-based handover algorithms. The Football video shows a typical snap, followed by a screen pass and ends with a fumble. The frame #180 from the Football video depicts the running player getting hit by a tackle from the adversary, as shown in Figure 7(a). The original frame has low quality, but SER and RSSI-based algorithms delivered such frame with similar quality to the original frame, as can be seen in Figures 7(b) and 7(c). PBGT and QoE-based algorithms delivered the frame with screen freezings/pixelization, as shown in Figures 7(d) and 7(e).

The Mobile video shows a train toy moving along the tracks and pushing a red ball, while other objects move at the screen. The frame #120 from Mobile video depicts the toy train moving in front of a calendar. The original frame sequence has a good quality, as depicted in Figure 7(f), but SER algorithm did deliver such frame with few blurred lines, as shown in Figure 7(g). RSSI-based could not achieve acceptable results, as observed from Figure 7(h) with the gray screen since previous frames were lost causing higher distortion in the video. PBGT and QoE-based obtained videos with few pixelizations as well, as seen in Figures 7(i) and 7(j).

Highway video shows a vehicle traveling along a highway with a green traffic sign on the right, as seen by Frame

#481 in Figure 7(k). Once again, the original and the delivered video by SER algorithm has almost identical quality, as shown in Figure 7(l). The RSSI-based algorithm did a good transmission with few pixelizations in Figure 7(m), while PBGT and QoE-based transmitted more deteriorated videos, as shown in Figures 7(n) and 7(o). Based on this subjective frame analysis, it is evident the benefits of the SER algorithm for video transmission compared to existing handover algorithm. The difference is explained by the fact that video transmitted by the PBGT, RSSI-based, and QoE-based algorithms are deteriorated, possibly by the constant frames loss, making the reconstruction impossible based on the previously received frames. These issues result in a deterioration of QoE of the user that is watching a video with pixelization and screen freezing.

5 | CONCLUSION

Mobile users produce, share, and consume real-time video services connected to a potentially HetNet infrastructure. The change among the different radio base stations that constitute such infrastructure needs an efficient handover decision to maintain the QoS/QoE for a mobile multimedia application. In this context, current handover algorithms consider only the signal strength and QoS for handover decision, which are not enough parameters to deliver videos with a high QoE. The use of distinct parameters is necessary to produce more efficient handover decisions to improve the performance of a mobile multimedia application.

In this article, we presented the SER (Service, Experience, and Radio) handover algorithm, which is based on MCDM to deliver video content service in HetNet with QoS/QoE support. The SER implements AHP technique to assign different degrees of importance to each parameter for handover decision. Simulation results show that SER delivered videos with 12% better QoE than videos delivered by existing handover algorithm.

For future work, we aim to include other criteria that can be used by SER for handover decision, such as network traffic on the serving and candidate cells, and mobile nodes speed consideration. Finally, functionalities anticipated by fifth generation networks (5G) can also be analyzed by SER algorithm, such as dual handover connectivity or the use of other challenging scenarios such as autonomous vehicle provision aided by infrastructure.

ACKNOWLEDGEMENTS

The authors would like to thank CAPES, CNPq, and FAPESPA for the financial support.

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TABLE 1 Main characteristic of handover algorithms

Work	QoS	QoE	Technique	Objectives
IEEE [19]	No	No	MIH	Padronization
3GPP [13]	No	No	RSSI-Based	Padronization
Dimou et al. [14,22]	Yes	No	PBGT	Better efficiency
Chaudhuri et al. [23]	Yes	No	Reinforcement Learning	Reduce Ping-Pong/handover failures
Xenakis et al. [25]	Yes	No	QoS-Based	Reduce interference/energy consumption
Zhang et al. [26]	Yes	No	Priority-Based	Reduce energy consumption
Liotou et al. [11]	No	Yes	QoE assessment	Better QoE provision
Chinnappan et al. [29]	Yes	No	AHP	Reduce handover
Drissi et al. [21]	Yes	No	AHP	Reduce delay/packet loss
Hussein et al. [30]	No	No	Fuzzy Topsis	Reduce Ping-Pong/failures

TABLE 2 Pairwise comparison for AHP

$C_{i,j}$	Degrees of Importance
1	Two criteria have the same importance
2	One criterion is more important than the other
3	One criterion is much more important than the other
1/2	One criterion is less important than the other
1/3	One criterion is much less important than the other

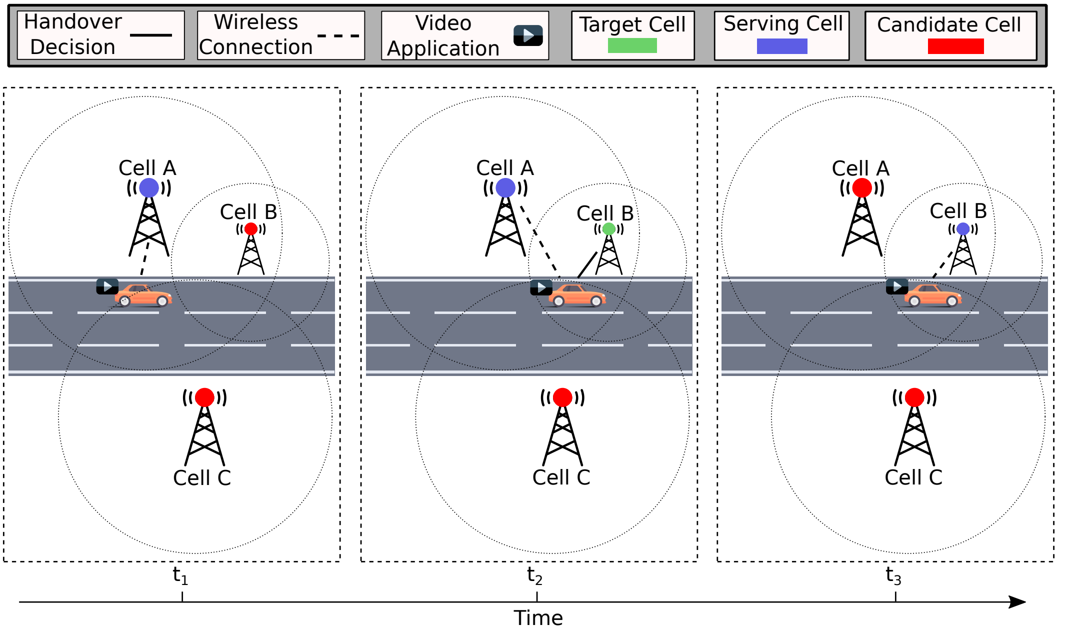
TABLE 3 Simulation parameters

Parameters	Values
Mobile Node Type [Speed in km/h]	Pedestrian [10], Car [75], Train [145]
Number of Nodes	90 (30 from each type)
Number of Macrocells Base Stations	2
Number of Small Cells Base Stations	11
Macrocell Transmission Power	46 dBm
Small cell Transmission Power	23 dBm
Number of LTE Resource Blocks	100
Modulation Mode	64 QAM
Macrocell Coverage Area	1 km^2
Small cell Coverage Area	75 m^2
Propagation Loss Model	Nakagami
PHY / MAC	3GPP LTE
Videos Used	Football, Mobile, Highway
Videos Characteristics	H.264, 30 fps, 352x288 pixels

dBm, decibel-milliwatts; QAM, quadrature amplitude modulation; fps, frames per second.

TABLE 4 Handover algorithms effectiveness

Algorithms	Number of Handovers	Standard Deviation	Ping-Pong Ocurrences (%)
SER	4.73	2	0%
RSSI-Based	44.95	5	50%
PBGT	1.22	2	0%
QoE-Based	1.10	2	0%

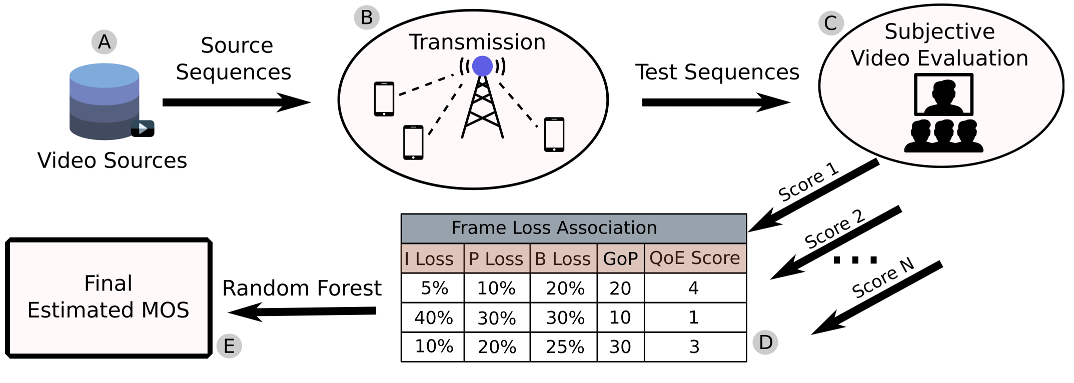


Cell	RSRQ	pMOS	PDR	AHP
A	-7	4	0.7	0.40
B	-15	5	0.2	0.28
C	-10	4	0.6	0.32

Cell	RSRQ	pMOS	PDR	AHP
A	-7	4	0.6	0.32
B	-8	5	0.8	0.35
C	-6	4	0.7	0.33

Cell	RSRQ	pMOS	PDR	AHP
A	-13	4	0.6	0.25
B	-5	5	0.8	0.41
C	-6	4	0.6	0.34

FIGURE 1 SER handover overview



I Loss	P Loss	B Loss	GoP	QoE Score
5%	10%	20%	20	4
40%	30%	30%	10	1
10%	20%	25%	30	3

FIGURE 2 QoE-monitor components

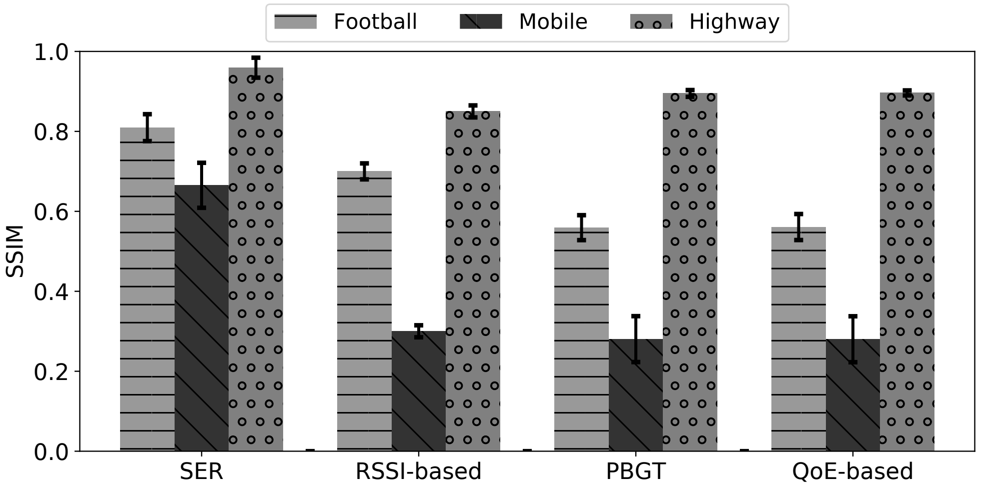


FIGURE 3 SSIM for videos delivered by different handover algorithms

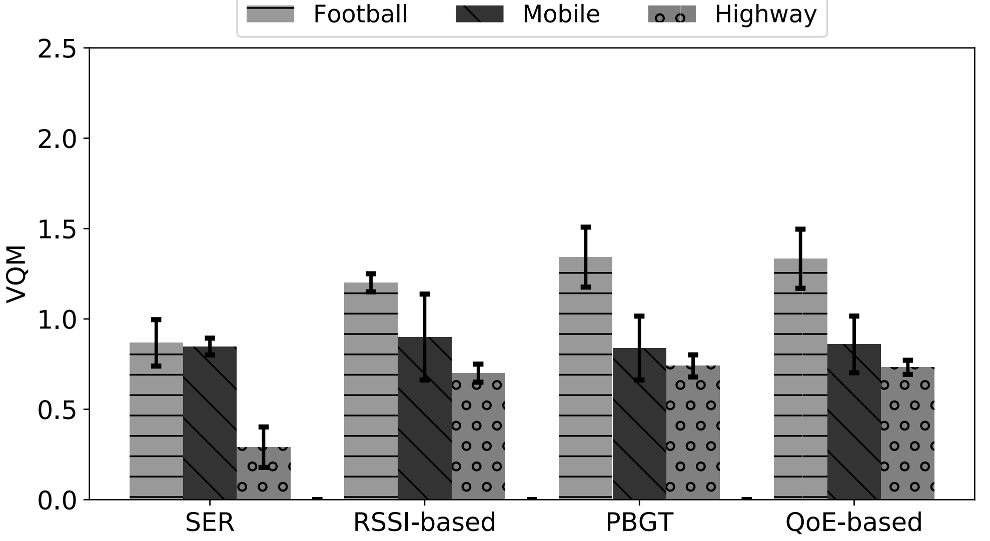


FIGURE 4 VQM for videos delivered by different handover algorithms

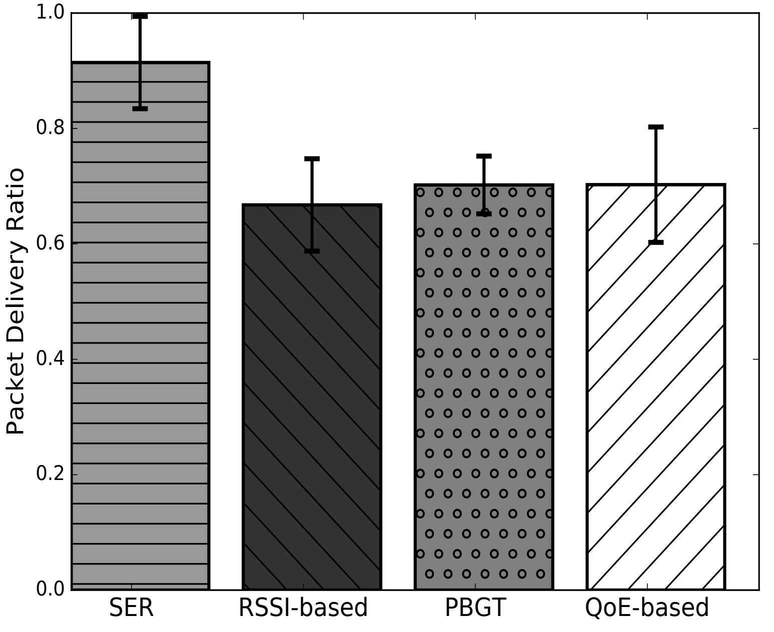


FIGURE 5 PDR for videos delivered by different handover algorithms

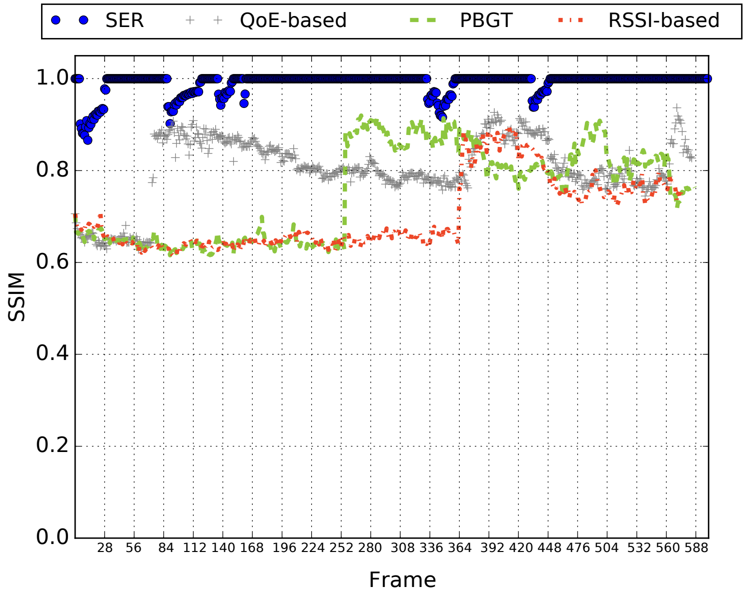
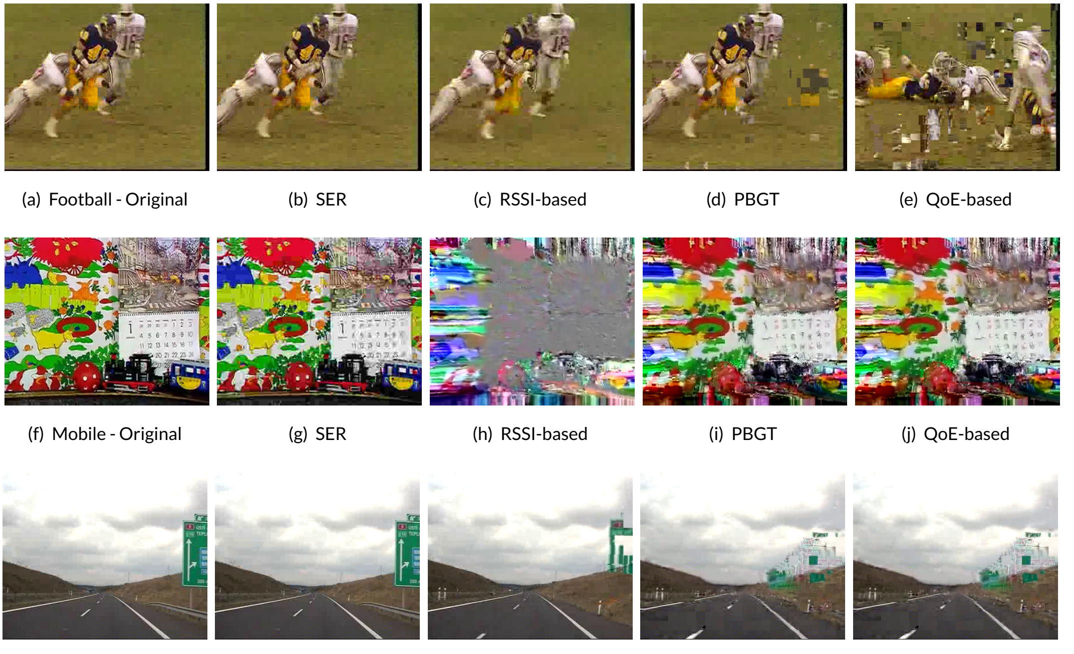


FIGURE 6 SSIM for all frames that compose the Highway video sequence



(a) Football - Original (b) SER (c) RSSI-based (d) PBGT (e) QoE-based

(f) Mobile - Original (g) SER (h) RSSI-based (i) PBGT (j) QoE-based

(k) Highway - Original (l) SER (m) RSSI-based (n) PBGT (o) QoE-based

FIGURE 7 Frame #180 from Football, Frame #120 from Mobile, Frame #481 from Highway