Assessment of a Robust Opportunistic Routing for Video Transmission in Dynamic Topologies

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Abstract—**Mobile multimedia ad hoc services run on dynamic topologies due to node mobility or failures and wireless channel impairments. A robust routing service must adapt to topology changes with the aim of recovering or maintaining the video quality level and reducing the impact of the user's experience. In those scenarios, beacon-less Opportunistic Routing (OR) increases the robustness by supporting routing decisions in a completely distributed manner based on protocol-specific characteristics. However, the existing beacon-less OR approaches do not efficiently combine multiple metrics for forwarding selection, which cause higher packet loss rate, and consequently reduce the video quality level. In this paper, we assess the robustness and reliability of our recently developed OR protocol under node failures, called cross-layer Link quality and Geographical-aware OR protocol (LinGO). Simulation results show that LinGO achieves multimedia dissemination with QoE support and robustness in scenarios with dynamic topologies.**

Index Terms—**Multimedia distribution, Opportunistic Routing, QoE support, and Robustness.**

I. INTRODUCTION

Multimedia ad hoc networks require real-time video transmission with low frame loss rate and tolerable end-to-end delay to enable video distribution with Quality of Experience (QoE) support. Such issues impose more constraints and design challenges to deliver real-time video flows with at least a minimum quality level [1]. In addition, those networks have a dynamic topologies caused by the failure or damage of an individual or group of nodes, or changes in the channel conditions. The topology changes might be temporary or permanent, causing different impact on network performance [2]. Hence, the routing service must adapt to topology changes and be aware of QoE requirements to recover or maintain video quality. Those issues make the design of a reliable and robust routing protocol a nontrivial task.

Several routing protocols have been proposed to meet the requirements to deliver multimedia content with QoE support under dynamic topologies. Those protocols are based on flat, hierarchical, or geographical approaches and rely on end-to-end routes to forward packets [3]. However, end-to-end routes might be subject to frequent interruptions or do not exist at any time in case of dynamic topologies. On the other hand, Opportunistic Routing (OR) increases network performance by making a distributed hop-by-hop routing decision based on protocol-specific characteristics [4]. OR relies on a coordination method at the receiver side to pick up the best candidate to forward packets. We consider both beacon-based and beacon-less modes as promising OR coordination methods, since they do not require stable end-to-end routes, enabling packet transmissions in case of dynamic topologies due to node failures and wireless channel variations.

In beacon-less OR [5-8], nodes do not need to be aware of their neighbours, avoiding beacon transmission and saving scarce resources, e.g., battery-power and bandwidth. To the best of our knowledge, the existing beacon-less OR approaches do not efficiently combine link quality, geographical information, and energy to build a reliable persistent route. For instance, protocols [6-8] consider only geographical information for routing decisions. However, due to the unreliability of the wireless channel, the most distant node might suffer from a bad connection. Those issues reduce the reliability, robustness as well as video quality level from user's perspective.

In this paper, we assess the reliability and robustness of LinGO [9] (a cross-layer Link quality and Geographical-aware beacon-less OR) under dynamic topologies caused by node failures and channel quality variations. Simulation results showed that LinGO provides multimedia dissemination with robustness, and QoE support with reduced overhead under both short (temporary) or long (permanent) topology changes. This is due to it combines multiple metrics for forwarding decisions, i.e., link quality, geographical information, and remaining energy, and also applies a video-aware mechanism to add redundant packets based on the frame importance.

The remainder of this paper is structured as follows. Section II outlines existing OR protocols and their main drawbacks. Section III presents the network model. Section IV describes LinGO. Section V discusses the simulation results. Section VI summarises the main contributions and results of this paper.

II. RELATED WORK

Heissenbüttel et al. introduced the idea of dynamic forwarding delay for forwarding decisions in the Beaconless Routing protocol (BLR) [5]. The source broadcasts the data packet. Before forwarding the received packet, possible forwarders within a forwarding area compute the forwarding delay based on location information. The node closest to the destination generates the shortest delay, and rebroadcasts the packet first.

Neighbour nodes recognize the occurrence of relaying, and cancel their scheduled transmission for a packet they overhear. Aguilar et al. introduced different forwarding areas, and considered a three-way handshake mechanism to determine the forwarder node [6]. Chen et al. combined application-level redundancy mechanism with a multipath scheme to increase robustness [7]. However, those protocols [5-7] rely on a single metric to compute the forwarding delay, reducing system reliability. In addition, protocols [6,7] include an extra overhead and delay for the three-way handshake mechanism.

The unreliable nature of wireless links makes it difficult to route packets in a dynamic wireless environment, since the wireless channel quality can be affected by several unknown factors, such as interference and fading. Hence, it is vital to consider the link quality for routing decisions [10]. Al-Otaibi et al. proposed a Multipath Routeless Routing protocol (MRR) [8], which defines a forwarding area as a rectangle and uses multiple metrics to compute the forwarding delay. However, when a given node receives a packet with weaker signals, it receives priority to forward packets, reducing the reliability and the video quality level. MRR also includes extra overhead and delay to find the destination location.

From our related work analysis, a cross-layer beacon-less OR approach is a promising solution for mobile multimedia ad hoc applications. This is because the nodes do not need to proactively broadcast beacon messages to be aware of their neighbours, saving scarce resources, e.g., battery and bandwidth. Moreover, it is essential to consider multiple metrics for the forwarding decision to assure robust and reliable video dissemination under dynamic topologies. However, all of these key features are not provided in a unified beacon-less OR proposal so far, and also existing proposals lack of robustness and QoE assessment in case of dynamic topologies.

III. SYSTEM MODEL

A. Network Model

We consider an ad hoc network composed of n nodes deployed in the monitored area. We assume that each node has an individual identity ($i \in [1, n]$), and those nodes are represented in a dynamic graph $G(V, E)$, where vertices V = $\{v_1, v_2, ..., v_n\}$ build a finite set of nodes, and edges E = $\{e_1, e_2, ..., e_m\}$ build a finite set of asymmetric wireless links between them. We define N(v_i) $\subset V$ as a subset of neighbours within the radio range of a given node v_i.

Each node v_i is able to estimate the link quality at the physical layer for a given link e_j, j = $1, ..., m$. For instance, the physical layer of CC2420 radio chip provides RSSI, Signal to Noise Ratio (SNR), and Link Quality Indicator (LQI) to estimate the link quality of each received packet [10].

We assume a network composed of one Destination Node (DN) equipped with a radio transceiver, an image decoder, and unlimited energy. Each node v_i is equipped with a camera, an image encoder, radio transceiver, and limited energy supply. Each node v_i has a battery with initial energy power (P_0) and it spends energy (P_{tx}) to transmit a packet, (P_{rx}) to receive a packet, and (P_v) to move with a certain speed (s). The speed ranges between a minimum (s_{min}) and a maximum (s_{max}) speed limit. Each node v_i is aware of its own location by means of GPS, or any other positioning service. Each v_i knows the DN location, since we assume a static DN.

The source Node (*SN*) is responsible for capturing video flows and transmitting them to the DN in a multi-hop fashion. At the beginning of every data transmission in beacon-less OR, the *SN* broadcasts video packets to its neighbours N(*SN*). In a completely distributed manner, one of those neighbours (RN_i, i = 1, ..., $|N(SN)|$) is selected as the forwarder node (F $\in$ N(*SN*)), i.e., next hop. Then, F repeats the same procedure until the video packet reaches the DN.

B. Failure Model

Mobile multimedia ad hoc scenarios might involve a dynamic topology caused by failures, damage, and/or mobility of nodes, as well as wireless channel variations. For instance, a node might have a physical (hardware) fault caused by natural phenomena, or when a node runs out of energy resources.

Channel variations also cause topology changes, since wireless transmissions often experience link error periods, and nodes may stop to overhear the transmission of each other. Several factors affect the propagation of wireless signals, contributing to channel impairments. Wireless transmission also suffers from interference by concurrent transmissions, coexisting networks, and other electromagnetic sources [10].

The persistence of node failures might be classified into permanent and transient, depending on their duration. We consider transient failures when a node resumes its operations after failure, otherwise we consider it as permanent failure [2].

IV. LINGO

In this section we describe LinGO, which efficiently combines multiple metrics to build reliable routes. In addition, LinGO relies on a QoE/video-aware mechanism to add redundant packets based on frame importance, enabling robust and efficient multimedia transmissions with reduced overhead. In this way, LinGO provides robust and reliable real-time video distribution with QoE support.

In contrast to LinGO, the existing beacon-less OR protocols do not efficiently combine link quality, geographical information, and energy to build reliable persistent routes. For instance, some protocols prefer RN_i closer to the DN to forward the packets [5-7]. However, the most distant node might suffer a higher packet loss rate due to the unreliability nature of the wireless channel. On the other hand, MRR prefers RN_i receiving a packet with weaker signals [8]. In addition, in contrast to previous works [5-8], LinGO introduces a different progress calculation, which takes into account the advance of a given RN_i towards DN with respect to *SN* and the radio range of RN_i. Thus, it reduces the number of required hops, bringing many benefits, such as reduced interference.

A. Multimedia Transmission

A compressed video is composed of I-, P-, and B-frames. From a human's standpoint, the loss of an I-frame causes error propagation through the other frames within a Group of Picture (GoP), since the decoder uses this frame as a reference point for the reconstruction of all the other frames within the same GoP. Thus, the video quality only recovers when the decoder receives an unimpaired I-frame. For the loss of a P-frame, the impairments extend to the remaining frames within a GoP, and the loss of P-frames at the beginning of a GoP causes higher video distortion than loss at the end of a GoP. The loss of a B-frame only affects the video quality of that particular frame.

The node constraints, such as bandwidth and battery, increase the effects of wireless channel errors, and packet-level redundancy mechanisms can be employed as an error-control scheme for handling losses in wireless communications. Thus, LinGO relies on a QoE/video-aware redundancy scheme [11] to achieve robust video transmission over a bandwidth-limited unreliable networking environment, since it considers Reed-Solomon coding to create redundant packets.

The QoE/video-aware redundancy mechanism adds r redundant packets to a set of k original video packets. It encodes h original video packets into a set of k coded packets by generating $(r = k - h)$ additional packets. The DN reconstructs k original video packets by receiving any h out of the k packets $(k > h)$. As soon as the DN receives k packets correctly, it may decode the frame immediately and drop the subsequent redundant packets. In contrast to many non-QoE approaches [7], this scheme adds redundant packets only for priority frames based on user's standpoint. Hence, it protects those frames in congestion or link error periods, and supports QoE-aware multimedia transmissions together with reduced overhead compared to existing redundancy schemes.

B. Contention-based Forwarding Mode

Whenever a *SN* wants to send a video flow, it triggers the contention-based forwarding mode by broadcasting the video packet to its neighbours N(*SN*). Before the *SN* transmits a video packet, it must determine its own location (x_{SN}, y_{SN}) and include it in the packet header, which contains the following information: <x_{SN}, y_{SN}, $PktId$, SN_{ID}, DN_{ID}>.

N(*SN*) compete to forward the received packet in a completely distributed manner, and LinGO tries to ensure that only one of them forwards the packet. This is accomplished by nodes computing a dynamic delay, and restricting the area in which nodes are allowed to forward the packet (forwarding area). In particular, upon receiving a packet, N(*SN*) know the *SN* location by analysing the packet header, and also N(*SN*) are aware of their own locations and the DN location. Thus, N(*SN*) can determine their forwarding area. LinGO divides the surrounding area of *SN* into Positive Progress Area (PPA) and Negative Progress Area (NPA), as shown Figure 1. PPA comprises the forwarding area, where N(*SN*) are closer to DN than *SN*. Otherwise, N(*SN*) are inside NPA.

N(*SN*) located within NPA must drop the received packet, since they are further away from DN than *SN*, and each node of N(*SN*) within the PPA is considered as possible forwarder. Instead of rebroadcasting the packet immediately, possible forwarders compute the Dynamic Forwarding Delay (DFD) value ranging from 0 to the maximum DFD (DFD_{Max}). Then, they must replace the *SN* location by their own locations in the packet header, set a timer according to the DFD, and wait for the timeout to rebroadcast the buffered packet. The node that generates the smallest DFD value rebroadcasts the packet first, and it is considered as a forwarder node (F).

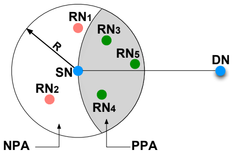


Fig. 1. Forwarding Strategy and Forwarding Area

Possible forwarders must cancel their scheduled transmission, and delete the buffered packet by overhearing a retransmission coming from F for the same $PktId$. At the same time, LinGO uses the rebroadcasted packet as passive acknowledgement, i.e., *SN* senses a retransmission for the same $PktId$ by F, and concludes that the packet was successfully received by F. Thus, *SN* forwards subsequent video packets explicitly addressed to F and without any additional delay. The algorithm continues until the packet reaches DN, which sends an explicit acknowledgement. In this way, LinGO finds a reliable route between *SN* and DN via multiple F.

The hidden terminal problem could appear, and thus RN_i and *SN* may be unable to overhear the packet transmission from F, preventing them to establish a persistent route. Route creation may also fail due to node mobility or when F does not have any RN_i inside the PPA. Hence, the *SN* must continue the contention-based forwarding mode, when *SN* does not overhear a packet transmission by any RN_i within DFD_{Max}. Otherwise, *SN* switches to persistent route mode.

C. Metrics for forwarding selection

Each RN_i computes the **DFD** based on Eq. (1) by taking into account multiple metrics, i.e., *link quality*, *geographical information*, and *remaining energy*. The proposed DFD prefers a given RN_i to forward the packet first when it is closer to DN, has a reliable link, and enough energy to forward subsequent packets. The DFD includes coefficients (α, β, and γ) to give weights to each metric. The sum of the coefficients $(\alpha + \beta + \gamma)$ is equal to 1. In the following, we explain how each RN_i computes $LinkQuality$, $progress$, and $energy$.

$$\text{DFD} = DFD_{Max} \times (\alpha \times \text{linkQuality} + \beta \times \text{progress} + \gamma \times \text{energy}) \quad (1)$$

1) Metric 1 definition - Link quality: LinGO considers the link quality between nodes as part of DFD in order to provide reliable transmission, and computes it according to Eq. 2.

$$\text{LinkQuality} = \begin{cases} 0 & \text{if } LQE_t >= LQE_{Good} \\ \frac{LQE_{Max} - LQE_t}{LQE_{Max}} & \text{if } LQE_{Bad} < LQE_t < LQE_{Good} \\ 1 & \text{if } LQE_t <= LQE_{Bad} \end{cases} \quad (2)$$

Link Quality Estimation (LQE_j) denotes a single value for the immediate link quality for a given link e_j connecting a pair $(SN, RN_i) \in V$. LQE_j is computed by RN_i for each received packet in contention-based forwarding mode. LinGO could consider RSSI, SNR, or LQI for LQE_j, ranging from a minimum LQE$_{Min}$ to a maximum LQE$_{Max}$ value. We consider LQI. The LinkQuality function ranges from 0 to 1, and a given link e_j with low LQE$_j$ value produces a higher LinkQuality value, which reduces the likelihood to choose such RN_i. This is because a route with low LQE$_j$ cannot provide reliable multimedia transmission.

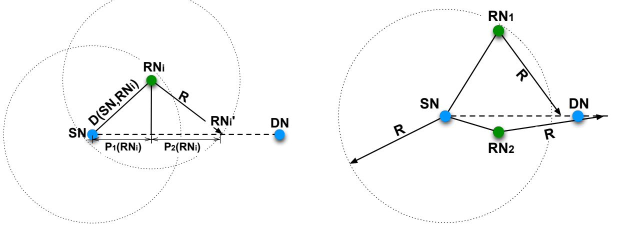
Baccour et al. classified the links according to the values of Packet Reception Ratio (PRR) into three regions of connectivity, namely connected (PRR higher than 90%), transitional (PRR between 10% and 90%), and disconnected (PRR lower than 10%) [10]. Hence, we defined the bounds of disconnected and connected regions by means of two LQE thresholds (LQE$_{bad}$ and LQE$_{good}$) determined on experiments. In this way, we can classify a link e_j as disconnected, as soon as a given RN_i received a packet with LQE$_j$ lower than LQE$_{bad}$; or as connected when LQE$_j$ is higher than LQE$_{good}$; or as transitional for LQE$_j$ ranging between LQE$_{bad}$ and LQE$_{good}$.

A given RN_i with a connected link to *SN* has a higher probability to forward the packet faster (i.e., $LinkQuality$ = 0), since this node has higher reliability to transmit packets. For disconnected links, $LinkQuality$ returns 1, making a given RN_i less likely to forward the packet faster, due to the lower PRR provided by such link. A transitional link generates $LinkQuality$ value ranging from 0 to 1.

2) Metric 2 definition - Progress: We define progress as the geographical advance of a given RN_i towards DN with respect to *SN*, i.e., a given RN_i with large progress means a node closer to DN. We compute progress according to Eq. 3.

$$\text{progress} = \begin{cases} \frac{2R - P(RN_i, DN)}{2R} & \text{if } D(RN_i, DN) > R \\ 0 & \text{if } D(RN_i, DN) <= R \end{cases} \qquad (3)$$

We denote $D(RN_i, DN)$ as the distance between a given RN_i and DN, R as the radio range, and $2R$ as the maximum progress. The sum of two segments ($P_1(RN_i)$ + $P_2(RN_i)$) composes the progress ($P(RN_i, DN)$) of a given RN_i, as shown in Figure 2(a). We define $P_1(RN_i)$ as the projection of the distance travelled from *SN* to any RN_i, onto the line from *SN* to DN. On the other hand, the projection of line RN_i-RN_i' onto line *SN*-DN defines $P_2(RN_i)$.



(a) Definition of Progress (b) Progress for Multiple RN_i

Fig. 2. Definition of Progress with Potential RN_i

Existing work [5-7] defined progress as $P_1(RN_i)$, which may cause collisions. This is because multiple RN_i can have the same progress, i.e., $P_1(RN_1)$ = $P_1(RN_2)$, as shown in Figure 2(b). Thus, those nodes rebroadcast the packet at the same time. However, we solve such problem in our progress definition. For instance, RN_2 is closer to the line *SN*-DN, increasing the progress value in our definition. *SN* can also transmit the video packets to DN via RN_2 with only one hop, which cannot be achieved by RN_1.

The proposed $Progress$ function gives higher priority to any RN_i, as soon as it is able to transmit packets directly to the DN. Relaying packets by intermediate nodes is often not more energy-efficient than direct transmission. Otherwise, RN_i with larger progress generate lower input to DFD, increasing the probability to forward the packet faster.

3) Metric 3 definition - Energy: Battery-powered nodes should consider energy for forwarding selection to provide energy-efficiency support. Thus, we propose to compute the energy according to Eq. 4.

$$\text{energy} = \begin{cases} \frac{E_0 - RE_t}{E_0} & \text{if } RE_t >= E_{Min} \\ 1 & \text{if } RE_t < E_{Min} \end{cases} \qquad (4)$$

E_{min} indicates the sum of energy required to transmit packets (E_{tx}) and move (E_v). For instance, RN_i need (E_{tx} = $k' \times P_{tx}$) to transmit a given number of k' packets. Moreover, in case of mobile nodes, RN_i require (E_v = s × P_v) to move with a certain speed s. Thus, a given RN_i has priority to forward the packet, when it has enough remaining energy (RE_t) to forward subsequent video packets, and if needed move back to the control centre for battery replacement.

D. Persistent Route Mode

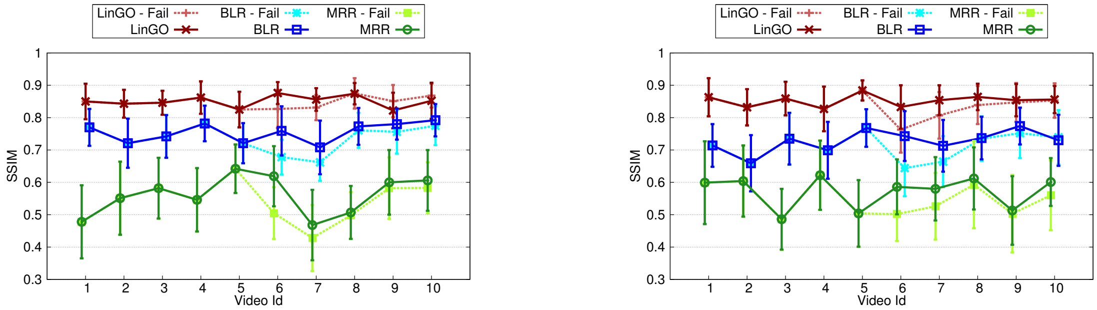
Transmitting all packets in contention-based forwarding mode causes additional delays, interferences, and also DN receives more duplicate packets. This is because packets are broadcast over multiple forwarders F. Those issues reduce the video quality, being undesirable for mobile multimedia ad hoc applications. LinGO avoids the drawbacks of broadcast transmissions by introducing a persistent route mode, where it finds a persistent route between *SN* and DN via multiple F, as explained in Section IV-B. For the persistent route mode, nodes must transmit subsequent video packets explicitly addressed to F and without any additional delay. The persistent route mode lasts for a certain time period called Link Validity time Estimation ($LIVE$), as explained bellow.

The video content should be delivered even in presence of node failures, mobility, or channel variations. Hence, LinGO enhances its robustness by reconstructing periodically the persistent route to detect topology changes. We denote $LIVE$ as the time interval to reconstruct the persistent route. During the $LIVE$ interval, instead of broadcasting the packets, the nodes transmit video packets in a unicast fashion, and thus it avoids the mentioned problems of broadcast transmissions.

The $LIVE$ value should be adjusted according to the desired degree of robustness and energy consumption. From the energy consumption point-of-view, the persistent route reconstruction must occur with low frequency, i.e., high $LIVE$ value. On the other hand, high frequency of route reconstruction, i.e., low $LIVE$ value, provides better robustness.

V. PERFORMANCE EVALUATION

This section describes the methodology and metrics used to evaluate the quality level of transmitted videos under dynamic topologies. Next, it assesses the impact of temporary or permanent node failures on the video quality.



(a) $LIVE$ = 2

(b) $LIVE$ = 4

Fig. 3. Video quality level for a scenario with 30 nodes, transient node failures, and different $LIVE$ values

A. *Simulation Description and Evaluation Metrics*

We used the Mobile MultiMedia Wireless Sensor Network (M3WSN) OMNeT++ framework [12]. The simulations last for 200 seconds (s) and run with the lognormal shadowing path loss model. We set the simulation parameters to have temporary wireless channel variations, link asymmetry, and irregular radio ranges, as expected in a real wireless network environment. In our simulations, *SN* sends the first video sequence of 10s at 4s of the simulation time, and transmits a new video every 20s. Thus, we obtain a total number of 10 video transmissions per simulation. The results are averaged over 33 simulation runs with different randomly generated seeds to provide a confidence interval of 95%.

We denote (x, y) as the node coordinates. In our simulations, a network topology is generated with the DN located at one side of the area $(38, 38)$, the *SN* located at the other side $(5, 5)$, and $(n-2)$ nodes randomly located over the entire flat terrain of 40×40 m. The nodes are equipped with CC2420 radio, and use the transmission power of -15 dBm. They rely on the classical CSMA as a MAC protocol. We encoded the video with typical parameters for a natural disaster recovery application, i.e., H.264 codec at 200 kbps, 30 frames per second, and in a quarter common intermediate format (176x144). The decoder uses Frame-Copy as the error concealment method to replace each lost frame with the last received one, making less severe impact of frame losses on the video quality.

The DFD weights (α, β, and γ) affect the LinGO performance. We optimized results shown in [9], and concluded that α = 0.5, β = 0.4, and γ = 0.1 give the best LinGO results. This is because LinGO achieved the best trade-off between high progress towards DN together with reliable links and enough energy to forward the packets with an acceptable video quality. In addition, we set the DFD_{Max} to 50 ms.

We measure the video quality by means of a well-known objective QoE metric, i.e., Structural Similarity (SSIM). It is based on frame-to-frame assessment of three video components: luminance, contrast, and structural similarity. It ranges from 0 to 1, and a higher value means better video quality.

B. *Reliability and Robustness Evaluation*

We evaluate the reliability and robustness of LinGO compared to BLR and MRR by deploying static nodes, and the dynamic topologies are caused by individual node failures and wireless channel variations, as explained in Section III-B.

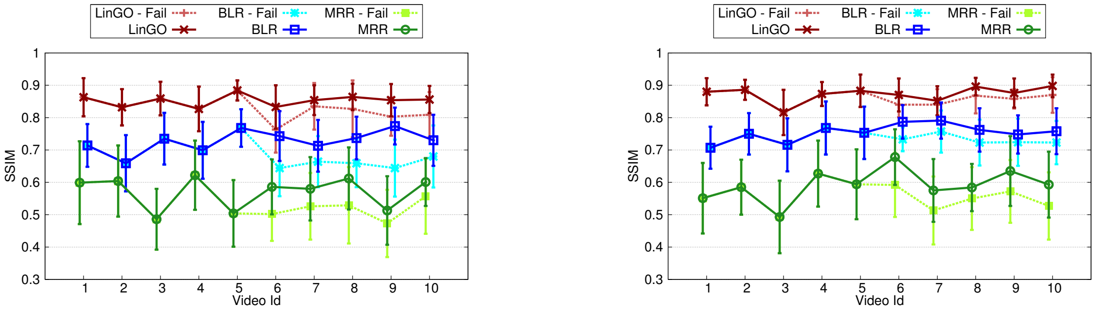
We defined two scenarios, where one has temporary node failures and another one has permanent node failures. For both scenarios, we created the worst-case for topology changes, where the *SN* established the persistent route and 10% of 1-hop neighbours of *SN* have node failures, which last temporarily or permanently, as explained in the next sections. We also performed simulations by failing 10% 1-hop neighbours of DN. Due to restricted space of this paper, those results are not shown, but they also confirm the robustness of LinGO.

1) ***Impact of Transient Node Failures****:* Figure 3 shows the video quality for 10 videos transmitted with and without transient node failures, where the transient node failures happened during the transmissions of videos 6 and 7. This explains the similar video quality level for videos 1 - 5 and 8 - 10 for scenarios without any node failures regardless of the protocol.

In contrast to BLR and MRR, LinGO without node failures keeps the video quality high and constant, i.e., $SSIM$ around 0.87 for videos 1 - 10. LinGO also has smaller confidence intervals than MRR and BLR, i.e., a small variation in the video quality for different random-generated seeds. This is explained because LinGO is able to build reliable persistent routes, protecting key frames during link error periods. For instance, LinGO reduces by up to 50% the loss of I- and P-frames compared to BLR and MRR, which are the priority frames and their loss increase video distortion. Hence, LinGO enables video dissemination with QoE support in scenarios with dynamic topologies caused by channel quality variations.

During the transmission of video 6, nodes established persistent routes and 10% of network nodes have transient failures lasting until the end of video 7. Besides the topology changes caused by node failure, a burst of packets might be lost until the *SN* re-establishes a persistent route, since one of the nodes from the persistent route might not be available anymore to forward packets. In the worst case, this lasts for the $LIVE$ interval, because this is the interval for route reconstruction.

Figure 3(a) shows that the video 6 transmitted via LinGO in presence of node failures (LinGO - Fail) decreases its quality by 5% compared to the scenario without node failures (LinGO). It is important to notice that the video quality is still better than BLR and MRR without any node failure, since LinGO reconstructed a reliable persistent route even when the



(a) Scenario with 30 nodes

(b) Scenario with 40 nodes

Fig. 4. Video quality level for a scenario with $LIVE$ value of 4s, permanent node failures, and different node density

topology change is caused by transient node failures. Video 6 transmitted via BLR and MRR with transient node failures decreased the video quality by up to 10%, compared to video 6 transmitted via BLR and MRR without any node failures, because those protocols are not able to re-establish a reliable persistent route in case of topology changes.

We can compare the results of Figure 3(a) and 3(b) to analyse the impact of the $LIVE$ value, since the $LIVE$ value affects the degree of robustness. By doing so, we can see that the scenario with a $LIVE$ value of 4s degrades the video quality more compared to a scenario with a $LIVE$ value of 2s. This is because in case of node failures, the $LIVE$ value of 4s has a longer burst of lost packets compared to a $LIVE$ value of 2s. Thus, those issues cause higher packet loss, which decreases the video quality level. It is important to note that we choose a $LIVE$ value of 4s for the next simulations, because we also want to evaluate the protocols for worst-case scenarios.

*2) **Impact of Permanent Node Failures**:* Figure 4 shows the video quality for networks with 30 and 40 nodes, with and without permanent node failures. The permanent node failures happened during the transmissions of videos 6 - 10.

LinGO transmits video 6 with similar quality level compared to BLR without any node failures for a network with 30 nodes. Moreover, LinGO in presence of permanent node failures recovered the video quality for videos 7 - 10, since LinGO adapted better to topology changes. On the other hand, BLR and MRR under failures reduce the video quality more compared to LinGO. Moreover, BLR and MRR do not recover the video quality as LinGO does for transmitting videos 7 - 10. In addition, the impact of node failures decreases when the node density increases. This is because nodes have more neighbours, increasing their likelihood to reconstruct a reliable route, and thus enable nodes to adapt to topology changes.

VI. CONCLUSIONS

This paper assessed the robustness and reliability of LinGO for video dissemination in case of dynamic topologies. LinGO enables real-time video transmission with QoE assurance, because it establishes a reliable persistent route and reacts better to node failures. Additionally, it transmits redundant packets to achieve robust video delivery. The simulations results showed that LinGO provides multimedia dissemination with robustness and QoE support in presence of dynamic topologies caused by node failures or wireless channel changes. We concluded that both BLR and MRR perform poorly compared to LinGO in dynamic scenarios. This is due to LinGO efficiently combines multiple metrics to build reliable routes, and also it relies on a QoE-aware mechanism to add redundant packets.

VII. ACKNOWLEDGMENTS

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