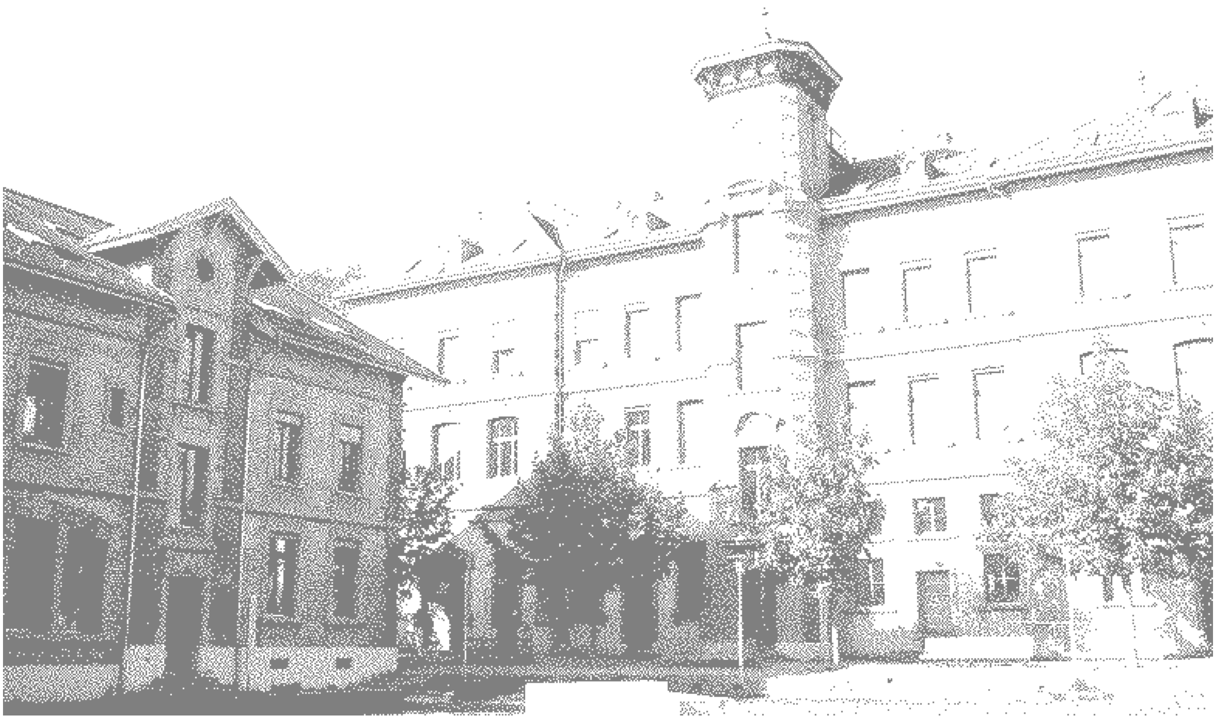
UNIVERSITÄT
BERN

A Link Quality and Geographical-aware Routing Protocol for Video Transmission in Mobile IoT

Denis Rosario, Zhongliang Zhao, Eduardo Cerqueira, Torsten Braun, Aldri Santos.

Technical Report IAM-13-001 , March 28, 2013

Institut für Informatik und angewandte Mathematik, www.iam.unibe.ch



A Link Quality and Geographical-aware Routing Protocol for Video Transmission in Mobile IoT

Denis Rosário, Zhongliang Zhao, Eduardo Cerqueira, Torsten Braun, Aldri Santos

***Abstract*—Wireless mobile sensor networks are enlarging the Internet of Things (IoT) portfolio with a huge number of multimedia services for smart cities. Safety and environmental monitoring multimedia applications will be part of the Smart IoT systems, which aim to reduce emergency response time, while also predicting hazardous events. In these mobile and dynamic (possible disaster) scenarios, opportunistic routing allows routing decisions in a completely distributed manner, by using a hop-by-hop route decision based on protocol-specific characteristics, and a predefined end-to-end path is not a reliable solution. This enables the transmission of video flows of a monitored area/object with Quality of Experience (QoE) support to users, headquarters or IoT platforms. However, existing approaches rely on a single metric to make the candidate selection rule, including link quality or geographic information, which causes a high packet loss rate, and reduces the video perception from the human standpoint. This article proposes a cross-layer Link quality and Geographical-aware Opportunistic routing protocol (LinGO), which is designed for video dissemination in mobile multimedia IoT environments. LinGO improves routing decisions using multiple metrics, including link quality, geographic location, and energy. The simulation results show the benefits of LinGO compared with well-known routing solutions for video transmission with QoE support in mobile scenarios.**

***Index Terms*—Internet of Things, Multimedia distribution, New IoT applications, Node mobility.**

I. Introduction

In recent years, multimedia applications have attracted research interest for smart cities scenarios, and encouraged the development of new Internet of Things (IoT) architectures, protocols, and applications. The multimedia data in such applications aims to protect human lives and infrastructure, while reducing emergency response times for security and environmental monitoring applications. Video flows of a disaster or crime scene provide users and authorities (e.g., polices) more precise information than scalar data and allow them to take appropriate action [1]. For instance, Robots or Unmanned Aerial Vehicles (UAV) could have been used during/after the Hurricane Sandy in New York/USA (2012) or flooding in Rio de Janeiro/Brazil (2013) to collect real-time video flows to guide search and rescue operations.

In security and environmental monitoring systems, the video flows collected by the sensor nodes (as well as the placed in robots and UAVs) must be transmitted with Quality of Experience (QoE) assurance [2] to headquarters or IoT platforms (e.g., [3], i-SCOPE, and Sight Machine) for further processing and analysis. Thus, it will be possible to extract valuable visual information and to take appropriate actions. In this study, we focus on how to collect video flows from wireless sensor-based multimedia networks to feed smart cities/IoT platforms.

The transmission of multimedia content (e.g., audio and video streaming, or still images) introduces additional characteristics and design challenges compared to those in scalar data transmission. This is due to the nature of the multimedia transmission, which requires high bandwidth demand and QoE support to deliver multimedia content with at least a minimum level of video quality from the user's perspective [2]. Moreover, advances in mobile communications enhance multimedia IoT scenarios with mobility support for either objects or nodes or both. Robots or UAVs equipped with a sensor camera might be responsible for retrieving multimedia data from the monitored environment [4]. Thus, these issues make the design of efficient protocols for mobile multimedia IoT a nontrivial task. Additionally, node mobility imposes additional restrictions to enable multimedia transmissions with QoE support in mobile IoT scenarios.

Routing protocols based on opportunistic schemes assume that an end-to-end route may be subject to frequent interruptions or does not exist at anytime, as expected in mobile IoT scenarios. This class of routing mechanisms allows nodes to forward the packets to the destination on the basis of a hop-by-hop decision without a stable end-to-end route from source to destination [5]. Opportunistic routing improves the communication performance by exploiting the broadcast nature and the spatial diversity of the wireless medium. The source node broadcasts packets, and the neighbour nodes within the source node radio range, assign a role to decide which node should forward the packets [6].

In the context of opportunistic routing for mobile multimedia IoT applications, a beacon-less approach appears to be an excellent routing solution. The reason for this is that the sender does not need to be aware of its neighbours (e.g., as expected for disaster scenarios), which avoids beacon transmission, and consequently saves scarce resources [7]. A beacon-less routing approach includes a dynamic delay for the possible relay node before forwarding the packet, which has a low value and helps the process to find routes in a fully distributed manner. However, the relay node must provide a higher progress towards the destination with respect to the last hop. At the same time, the most distant node might suffer from bad link quality, due to the unreliable nature of the wireless links that often experience

D. Rosário and E. Cerqueira are with Federal University of Pará, Belém, Brazil. e-mail: {denis, cerqueira}@ufpa.br

D. Rosário, Z. Zhao and T. Braun are with Institute of Computer Science and Applied Mathematics, University of Bern, Switzerland. e-mail {rosario, zhao, braun}@iam.unibe.ch,

A. Santos is with Federal University of Paraná, Curitiba, Brazil. e-mail aldri@inf.ufpr.br

Manuscript received January 31, 2013

significant link quality fluctuations and weak connectivity, which causes a high packet loss rate [8]. Hence, a reliable and efficient beacon-less routing protocol must consider multiple metrics to compute the dynamic delay to provide the best trade-off between higher progress and reliable links. In this way, it is possible to enable multimedia dissemination with QoE support, even if the topology continuously changes.

To address the above issues, we propose a cross-layer Link quality and Geographical-aware Opportunistic Routing protocol for video transmission in mobile multimedia IoT environment, called LinGO. Our protocol provides high progress together with a reasonable link quality to enable multimedia dissemination with QoE support in scenarios with topology changes due to nodes mobility, such as required for many safety and environmental monitoring IoT applications. LinGO takes into account key cross-layer metrics to compute the delay function, i.e. link quality, progress, and remaining energy.

The impact and benefits of LinGO for video dissemination in mobile multimedia IoT applications was shown by carrying out simulations to evaluate the quality of transmitted videos from the perspective of the user's experience. We analysed the video quality by means of two QoE objective metrics, namely Structural Similarity (SSIM) and Video Quality Metric (VQM), as well as by subjective metric, i.e. Mean Opinion Score (MOS). By analysing the results, we can conclude that LinGO provides a VQM gain of around 30% compared to the well-known existing routing solutions. Thus, LinGO enables multimedia distribution with a high level of video quality in dynamic scenarios due to topology changes, as expected for many mobile multimedia IoT applications.

The remainder of this article is structured as follows. Section II outlines existing opportunistic routing protocols. Section III describes the proposed Link quality and Geographical-aware Opportunistic routing protocol for mobile IoT applications, which was evaluated by means of simulation experiments (as outlined in Section IV). Section V summarises main contributions and results of the article.

II. Related Work

Opportunistic routing protocols allow the routing decision in a completely distributed manner, by using a hop-by-hop route decision. Possible forwarders decide to forward the received packets based on protocol-specific characteristics. This is usually achieved by transmitting beacon messages to create and order a relay candidate list according to certain criteria, such as expected transmission count [9]. On the other hand, Mao et al. presented an energy-efficient opportunistic routing strategy, which focuses on selecting and prioritizing the forwarder list to optimize the network performance [10]. However, the existing protocols that are base on candidate list do not provide reliability in mobile environments. This is because the predefined candidate list may not be applicable when the nodes move or due to wireless environment changes. In this context, a beacon-less approach improves performance of mobile multimedia networks, because it avoids periodic beacon transmission, and thus saves scarce resources.

The Beacon-less Routing protocol (BLR) uses location information to minimize the routing overhead by eliminating periodic beacon messages [7]. BLR introduces the idea of a dynamic delay timer, which is computed by using location information. The node with the most forwarding progress generates the smallest delay rebroadcasts the packet first, and the neighbour nodes recognize the occurrence of packet transmission and cancel their scheduled transmission of the same packet. Other proposals have also classified the candidates list according to their distances to the destination, such as [11], [12]. However, these works rely on a single metric for routing decisions, i.e., geographic information, which decrease the reliability and system performance. On the other hand, Al-Otaibi et al. proposed a Multipath Routeless Routing protocol (MRR), which uses multiple metrics to compute a dynamic delay [13]. Although, MRR defines a forwarding area as rectangle, and the proposed formula preferring nodes located closer to the borders of the rectangle (not progress towards the destination), which introduces more hops, additional delay, and reduces the reliability. Additionally, MRR includes an extra overhead and delay for the location update mechanism to finds the location of a mobile base station.

Lu et al. introduced an analytical model to study the performance of multi-hop video streaming through an opportunistic approach, and also showed the benefits of using opportunistic routing to disseminate video content [14]. Seferoglu et al. proposed a video-aware opportunistic network coding schemes that take into account both the decodability of the network codes by several receivers and the importance of video packets deadlines [15]. Nevertheless, both proposals rely on a fixed candidate list approach, which reduces system performance and is not suitable for dynamic IoT scenarios. These solutions also lack on a QoE-based evaluation to show the real impact of their schemes on the user perception.

The unreliable nature of wireless channels in mobile IoT makes it difficult to route packets in a wireless environment, since the quality of the wireless channel might be affected by many unknown factors, such as interference, fading, and others. Hence, it is vital to take the link quality of wireless links into account when designing a beacon-less routing protocol for mobile multimedia IoT applications. In this context, Srinivasan et al. showed that the link quality fluctuates over time and space [16]. Zhou et al. showed that wireless links are typically asymmetric [17]. Chen et al. used a historical Received Signal Strength Indicator (RSSI) as a routing metric to enhance the BLR performance, by avoiding routing into sparse areas [18].

From an analysis of related work, we conclude that existing opportunistic routing protocols do not take into account all of these relevant characteristics in a unified routing proposal to support QoE-aware multimedia transmission in IoT scenarios. It is essential to consider multiple metrics so that a joint routing decision can be made for opportunistic routing, and thus assure QoE support for video transmissions in a wireless environment with mobile nodes, as expected for mobile multimedia IoT applications.

III. The LinGO Protocol

This section details the cross-layer Link quality-aware Geographical Opportunistic routing protocol for video transmission in mobile multimedia IoT applications, called LinGO. This protocol finds reliable routes to transmit video packets, and thus increases the video quality from the user's perspective. LinGO adopts a Dynamic Forwarding Delay (DFD)-based approach, and takes into account multiple metrics to compute the DFD, i.e. link quality, progress, and remaining energy. Hence, LinGO provides high progress together with reliable links. In the next sections, we define the system model where LinGO can support mobile multimedia IoT applications with QoE support, and operational modes.

A. System Model

IoT applications require mobile nodes to monitor the environment as soon as the standard fixed network infrastructure is not available. In this context, multimedia content plays an important role in a future mobile IoT scenario to enable the end-users (or systems/platforms) to process and extract valuable information, such as object or intruder detection. Moreover, the end-users can visually determine the real impact of an event, and be aware of what is happening in the environment with the aid of valuable visual information.

This scenario can be applied to various applications, such as safety & security, environmental monitoring, and natural disaster recovery. For instance, in the case of a natural disaster, e.g. Hurricane Sandy in New York (2012), the recovery process requires the rapid and efficient deployment of a communication system to monitor the hazardous area by means of visual information. In this case, a group of mobile robots, or UAVs equipped with a camera could be used to set up a mobile multimedia network to save lives and help the rescue procedure. Hence, this mobile multimedia network enables to explore the hazardous area that rescuers cannot easily reach, as shown in Figure 1.

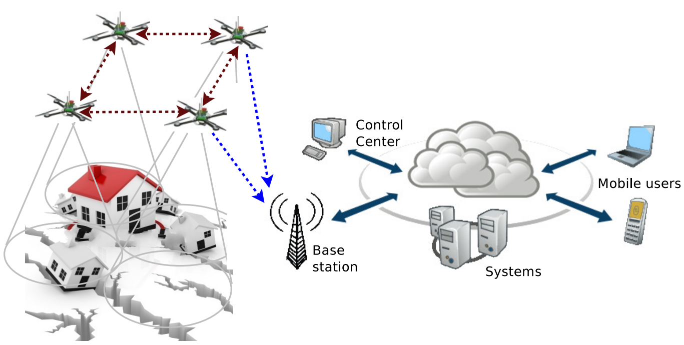


Fig. 1. IoT environment: a mobile multimedia network deployed in an emergency situation for smart cities scenarios

Let us assume a mobile multimedia IoT scenario composed of source, destination, and relay nodes. The Source Node (SN) is equipped with a complementary metal-oxide-semiconductor (CMOS) camera, and very low bit rate image encoder. SN is responsible for retrieving video flows and transmitting them to the Destination Node (DN). On the other hand, Relay Nodes (RN_i, i = 1, 2, ..., n) forward the packets from SN to DN, in a fully distributed manner among all possible RN_i, and without knowing the their existence or positions. In this article, we denoted multiple RN_i, as $RN_{i(s)}$.

With regard to the scenario described above, LinGO gives support for multimedia dissemination with at least a minimum video quality level from the user's perspective. In specific terms, LinGO selects reliable routes to transmit the multimedia data by means of two operational modes, namely greedy and unicast mode, which are explained in the next sections.

B. Greedy Mode

In the case of greedy mode, SN broadcasts the data packets to reach DN. Then, $RN_{i(s)}$ decide to forward the received packets, and LinGO ensures that only one RN_i forwards the packet on the basis of protocol-specific characteristics. LinGO gives priority to a RN_i with greater progress toward DN, higher link quality and enough energy to rebroadcast the packets, which is required for the outlined scenario. The nodes do not need to know their neighbour nodes because SN includes its geographic location and DN, in the packet header. Before forwarding the packets, $RN_{i(s)}$ must replace the previous node location with their current location in the packet header.

In this way, LinGO enables the $RN_{i(s)}$ to know their location, and also of the DN and last hop. As a result, $RN_{i(s)}$ can determine whether they are closer to the final destination. For example, RN_1 and RN_2 must drop the packets as they are further away from the DN compared to SN, as shown in Figure 2. On the other hand, RN_3, RN_4, RN_5 can be considered as possible relay nodes, because they allow progress towards DN with respect to node SN.

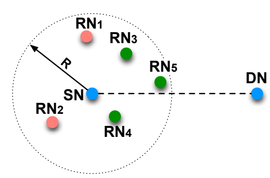


Fig. 2. Forwarding Strategy

These possible $RN_{i(s)}$ calculate the **DFD** value, and the RN_i that generates the smallest delay rebroadcasts the packet first. The neighbour $RN_{i(s)}$ recognize the occurrence of the relaying and cancel their scheduled transmission of the same packet. LinGO computes DFD according to (1), which considers metrics as *progress*, *remaining energy*, and *link quality*, to provide higher reliability and energy-efficiency. Additionally, DFD includes coefficients (α, β, and γ) so that it can give priority to each metric, and these values depend on the application requirements. The sum of coefficients ($\alpha+\beta+\gamma$) is equal to 1, and DFD_{Max} defines the maximum delay allowed for each $RN_{i(s)}$. Link Quality, Progress, and Remaining Energy are computed by means of (2), (3), and (4), respectively.

$$\text{DFD} = DFD_{Max} \times (\alpha \times \text{Link Quality} + \beta \times \text{Progress} + \gamma \times \text{Remaining Energy}) \tag{1}$$

By overhearing the transmissions, the $RN_{i(s)}$ cancel their scheduled transmissions of the same packet. At the same time, LinGO uses the rebroadcasted packet to acknowledge the successful reception of the current transmitting node. Hence the last hop knows which $RN_{i(s)}$ means the best network conditions to forward the packets. The operation continues until the packet reaches the DN, which has to send an explicit acknowledgement to the current transmitting node. This is because the DN does not forward the packet.

1) Link Quality: The existing beacon-less protocols assume successful transmissions as long as two nodes are within the transmission range of each other. These works assume identical channel quality at the time when they select and rank the candidate nodes. In the same way, as they do at the moment of packet transmission, which is not realistic due to the unreliable nature of the wireless links, as experienced in mobile multimedia IoT scenarios. In contrast, LinGO considers a Link Quality Estimation (LQE_t), e.g., RSSI or Link Quality Indicator (LQI), to compute the DFD function. The calculation of the "Link Quality" is established by Eq. (2), and LQE$_{Max}$ represents the maximum value for LQE.

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

A widely used off-the-shelf radio chip for IoT, i.e., CC2420, measures the LQE value by means of physical layer information. Thus, it provides the RSSI and LQI values for each received packet. In this context, LinGO uses the LQE by assessing different regions of connectivity provided by [8]. Baccour et al. classified the links by means of the PRR (Packet Reception Ratio) value into three regions of connectivity, namely connected (PRR higher than 90%), transitional (PRR between 10% and 90%), and disconnected (PRR lower than 10%). In specific terms, we define the bounds of disconnected and connected regions by means of two LQE thresholds (LQE$_{bad}$ and LQE$_{good}$), and must be selected based on setup experiments. LQE$_t$ lower than LQE$_{bad}$ implies a disconnected link, and LQE$_t$ higher than LQE$_{good}$ means a connected link.

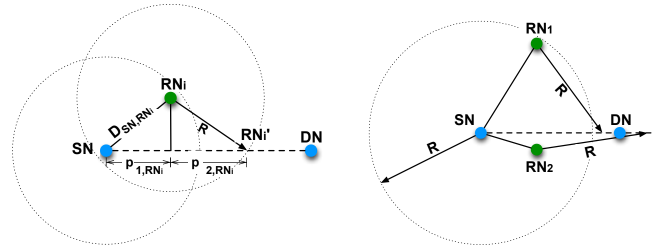
As soon as the $RN_{i(s)}$ receive a packet, they derive the LQE$_t$ and apply Eq. (2) to compute the "Link Quality". Based on the information outlined above, LinGO finds routes composed of links with higher PRR to support multimedia transmissions with QoE support. Thus, connected links return 0 to "Link Quality", which means that the connected link does not provide input to the delay function, increasing the probability that the node forwards the packet faster. Disconnected links return 1 as input to DFD, which makes it less likely to forward the packet. Finally, transitional links generate an output ranging from 0 to LQE$_{Max}$. A higher LQE$_t$ provides a lower input to the DFD.

2) Progress: $RN_{i(s)}$ compute their progress toward the destination with respect to the last hop, by using Eq. (3). As a result, a node with a higher progress generates a lower value, which means a small contribution to the DFD formula. P_{RN_i} means the progress of RN_i, R is the radio range, and D_{RN_i-DN} returns the distance between RN_i and D.

$$\text{Progress} = \begin{cases} \frac{2R-P_{RN_i}}{2R} & \text{if } D_{RN_i,D} > R \\ 0 & \text{if } D_{RN_i,D} < R \end{cases} \quad (3)$$

To clarify P_{RN_i}, let us assume three nodes: S, D, and a RN_i within the transmission range of S, as shown in Figure 3(a). The sum of two segments (p_{1,RN_i} + p_{2,RN_i}) composes the P_{RN_i}. The projection of line S-RN_i on line S-D defines the p_1 of RN_i, denoted as p_{1,RN_i}. On the other hand, the projection of line RN_i-RN_i' on line S-D defines p_2 of RN_i (p_{2,RN_i}). It should be highlighted that Eq. 3 introduces no delay for Eq. 1 (i.e., DFD function), as soon as DN is into the radio range of RN_i.

Some existing works, as [7], [11], [12], define progress as p_{1,RN_i}, which can cause collisions due to multiple $RN_{i(s)}$ can rebroadcast the packets at the same time. For example, in Figure 3(b), RN_1 and RN_2 generate the same forwarding delay, because p_{1,RN_1} = p_{1,RN_2}. However, in our definition of progress, RN_2 is closer to line SN-DN. Thus, it makes greater progress than RN_1. Therefore, in this case, SN can reach DN via RN_2 with only one hop, which cannot be achieved by the node RN_1 as the next hop.



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

Fig. 3. Definition of Progress with Potential RN_i

3) Remaining Energy: Battery-powered mobile nodes, e.g., UAVs, should consider energy to enable a routing decision with energy-efficiency support, as required in mobile multimedia IoT applications. Thus, we propose to compute the energy according to Eq. 4.

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

As a result, a node with high remaining energy (RE_t) compared to initial energy E_0 receives priority to transmit first, and thus introduces a low value in Eq. 1. LinGO gives priority to a RN_i if it has enough energy (E_{Min_1}) to send packets during the validity time of a link between neighbours (T_{LV}) (which is explained later). Additionally, after a RN_i transmits video packets during T_{LV}, $RN_{i(s)}$ must have enough energy (E_{Min_2}) to move back to the control center. This means that E_{min} is the sum of E_{Min_1} and E_{Min_2}. However, E_{Min_2} usually has more impact on E_{min}, since node movements demand more energy than packet transmissions.

C. Unicast Mode

Transmitting all multimedia packets in greedy mode causes additional delay and interference. Further, DN receives more duplicated packets, since they are broadcast over multiple $RN_{i(s)}$. These factors reduce the video quality level from the user's standpoint, being undesirable for mobile multimedia IoT applications with QoE support. In this way, LinGO avoids the drawbacks of broadcast transmission by introducing a unicast mode. In specific terms, by means of passive acknowledgment, as soon as a node detects the successful reception of the transmitted packet, it knows the RN_i with better network conditions to forward the next packets. Thus, the node must transmit subsequent packets using unicast, and the packets distributed in unicast mode do not include any additional delay.

Due to node mobility, the network conditions of the selected RN_i may change, and also another RN_i with better network conditions may enter into the node transmission range. Hence, LinGO must transmit packets in greedy mode after a certain time to detect these topology and network changes. LinGO also includes link validity estimation at every node to estimate the validity time (T_{LV}) of each link with its 1-hop neighbours.

Let us assume that every node knows its current direction and speed, e.g., with the help of GPS. By using the information collected from the neighbours (location and mobility), every node calculates the distance to its neighbours, and thus, it predicts the validity time of each link. For example, given two pairs of nodes i and j, which have the initial location (X_i,Y_i) and (X_j,Y_j), moving at a speed of V_i, V_j, and into the direction θ_i, θ_j, as shown in Figure 4. Hence, i and j can calculate T_{LV} for the link between them (Eq. 5).

$$R^2 = [(X_j + V_j \times \cos\theta_j \times T_{LV}) - (X_i + V_i \times \cos\theta_i \times T_{LV})]^2 \\ +[(Y_i + V_i \times \sin\theta_i \times T_{LV}) - (Y_j + V_j \times \sin\theta_j \times T_{LV})]^2 \quad (5)$$

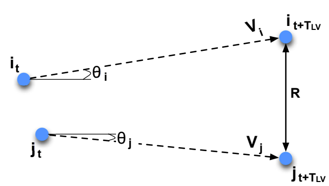


Fig. 4. An Example for Link Validation Time Calculation

D. Multimedia Transmission

Regarding multimedia transmission, frames with different priorities (I, P and B) compose a compressed video, and from human's experience the loss of high priority frames causes severe video distortion. The loss of an I-frame cause the errors propagating through the other frames within a Group of Picture (GoP), since the decoder depends of I-frame as a reference-point for all the other frames within a GoP. In this way, 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 of the GoP. The loss of a B-frame only affects the video quality of that particular frame.

In this context, the constraints of mobile nodes increases the effects of wireless channel errors, and application-level Forward Error Correction (FEC) can be employed as an error control scheme for handling losses in mobile multimedia IoT communications. Application-level FEC schemes achieve robust video transmission by sending redundant packets. In case of packet loss, the original frame can be recovered from the redundant information, which increases the video quality. Thus, a QoE-aware FEC mechanism [19] creates redundant packets by taking into account the frame importance from user's experience to increase the video quality, while reducing overhead and energy consumption. LinGO sends redundant packets by means of a QoE-aware FEC mechanism.

IV. Performance Evaluation

This section describes the simulations conducted to show the impacts and benefits of LinGO for video distribution with QoE support in mobile multimedia IoT applications. We outline the methodology used to evaluate LinGO and analyse the results reached.

A. Description and Evaluation Metrics

We evaluated LinGO through OMNeT++ simulations by using the extended version of Wireless Simulation Environment for Multimedia Networks (WiSE-MNet) Framework [19]. This framework provides a generic network-oriented simulation environment to address the need for a co-design of network protocols and distributed algorithms for mobile multimedia IoT applications. Simulations were carried out 33 times to provide a confidence interval of 95%. We compared the LinGO performance for video dissemination in mobile multimedia IoT application with well-known routing approaches, i.e., BLR and MRR. Table I summarizes the baseline simulation parameters.

TABLE I
Baseline simulation parameters

Parameter	Value	Parameter	Value
Field Size	50x50 m	Video sequence	Hall
Simulation Time	200 s	Video encoding	H.264
BS location	(25,0)	Video format	QCIF (176x144)
Tx power	-10 dBm	Frame rate	26 fps
Path loss model	Lognormal	Mobility model	Random way point
Radio model	CC2420	Node speed	5 m/s
T_{LV}	3 s	Node Number	30
DFD_{max}	50 ms		

QoE metrics/approaches overcome the limitations of Quality of Service (QoS) schemes regarding human perception and subjectivity. Several objective and subjective QoE metrics have been proposed to measure the video quality level based on the user's perspective [20]. For this reason, we measure the video quality of transmitted video with two well-known objective QoE metrics, namely Structural Similarity (SSIM) and Video Quality Metric (VQM), as well as by means of a subjective metric, i.e., Mean Opinion Score (MOS).

SSIM measures the structural distortion of the video to obtain a better correlation with the user's subjective impression. SSIM values range from 0 to 1, where a higher value means better video quality. On the other hand, VQM measures the "perception damage" based on features of the human visual system, including distinct metric factors, such as blurring, noise, colour distortion and distortion blocks. For VQM, a value closer to 0 means a video with a better quality. Despite objective metrics easily evaluate the video quality, they fail in capturing all the details that might affect user's experience, and thus, subjective evaluations are required. MOS is one of the most used metric for subjective video quality evaluation, means human observers rating the overall video quality. For MOS evaluation, we used the Single Stimulus (SS) method of ITU-R BT.500-11 recommendations. The viewers watch only once a video and then rate the video quality using the following scale: Bad; Poor; Fair; Good; and Excellent [20]. The choice of a SS paradigm is well suited to a large number of emerging multimedia applications, video on demand and Internet streaming.

B. LinGO Parameters

The coefficients (α, β, γ) of DFD function (Eq. 1) affect the LinGO performance. We employed the parameters in Table I, and defined 9 combinations with different coefficient values to show the performance of these combinations to choose one as a benchmark solution. The combination #1 only gives priority to progress (β) and thus ignores link quality (α) and energy (γ). The combinations #2 to #9 give the same priority to energy ($\gamma = 0.1$) since energy is not the most important metric in our experiments. These combinations differ from each other with regard to the priorities given to link quality (α) and progress (β), as shown in Table II. Figure 5 shows the measurements for video quality level, i.e. SSIM and VQM, for these 9 different coefficient combinations.

TABLE II
COEFFICIENTS COMBINATIONS FOR FORMULA (1)

Combinations #	α (Link Quality)	β (progress)	γ (Energy)
1	0	1	0
2	0.1	0.8	0.1
3	0.2	0.7	0.1
...	...	...	...
9	0.8	0.1	0.1

By analysing the results in Figure 5, we observe that the combination #1 has the worst performance for both SSIM and VQM results. This is because the nodes only consider progress to compute the DFD function, i.e. choose the relay node that provides greater progress towards the destination. It is worth noting that this combination is similar to existing approaches that only consider progress, such as [7], [11], [12]. However, the most distant node suffers from a poor channel quality due to the unreliable nature of wireless links, as experienced in mobile multimedia IoT scenarios. This leads to higher packet loss rate, and hence, bad video quality.

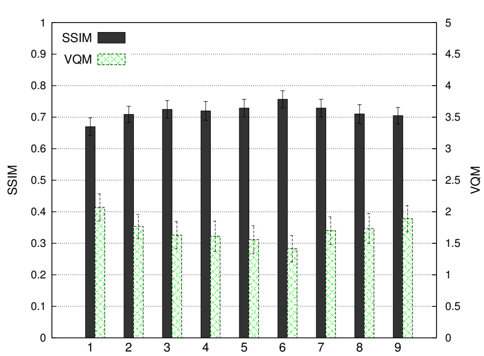


Fig. 5. Video quality level for different LinGO coefficient combinations

Combinations #2 to #9 perform better than combination #1. This is because they have different weights for link quality and progress. Thus, by tuning the coefficients for link quality and progress, LinGO can achieve the best trade-off between progress and link reliability, which is achieved by combination #6. For these reasons, we choose the worst (#1) and the best (#6) LinGO combinations to compare with BLR and MRR. Afterwards, we performed simulations to show the benefits of QoE-aware FEC mechanism for LinGO, BLR, and MRR, as shown in Figure 6. Due to space limitations and to easily analyse the results, the SSIM results are not presented for the next simulations scenarios. It is important to highlight that the SSIM results confirm the VQM results.

Figure 6 shows that QoE-aware FEC mechanism improves the video quality by around 50%. This happens because node mobility increases the packet loss rate, and the redundant packets enable to reconstruct a lost frame, improving the video quality from a user's perspective.

Moreover, BLR outperforms LinGO(#1), due to BLR defines a forwarding area so that only the nodes within the area are forwarding candidates, decreasing the coordination overhead, and thus improves performance. On the other hand, LinGO(#6) improves the video quality by around 40% compared to LinGO(#1), BLR and MRR. This occurs because LinGO(#6) uses multiple metrics to compute DFD, which reduces the packet loss rate and hence improves the video quality. This is achieved by including the information about link quality with the aims to find reliable routes to reduce the packet loss. Finally, the worst performance of MRR is due to the formula, as explained in Section II.

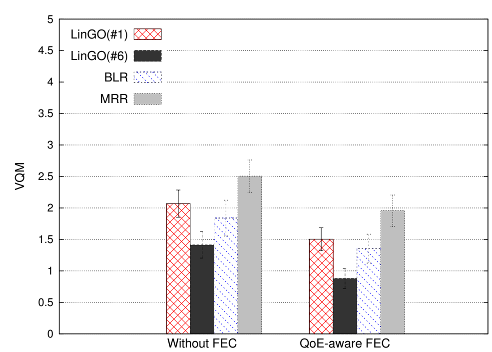


Fig. 6. Impact of QoE-aware FEC mechanism for different routing protocols

The QoE-aware FEC mechanism improves the video quality level by creating redundant packets based on frame importance to recover a lost frame. Therefore, in the following simulation scenarios we will use the QoE-aware FEC mechanism for LinGO, BLR, and MRR protocols. Additionally, LinGO(#6) provides the best trade-off between high progress and reliable links, and thus only this LinGO combination is applied for the next simulation experiments.

C. Impact of Moving Speed

The simulations conducted for this section contain the parameters of Table I. We also defined three different moving speeds (1, 5, and 10 m/s, which are expected speeds for typical UAVs) to evaluate their impact on the final video quality level, as shown in Figure 7. As soon as there is an increase in the speed of the nodes, the video quality decreases. This is because RN_i may move out of the transmission range of the last hop, which causes packet losses. To detect such situation, LinGo, BLR, and MRR rely on a link validation time to detect RN_i with better network conditions.

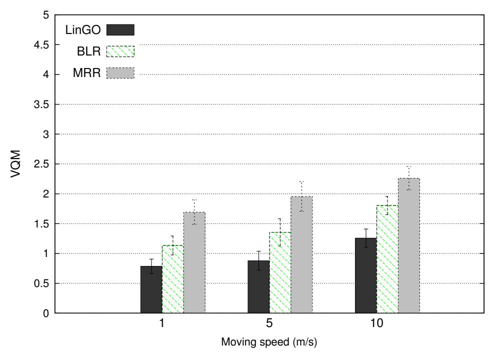


Fig. 7. Impact of moving speed on different protocols

LinGO outperforms BLR and MRR for these three scenarios. Due to BLR only uses progress to compute the DFD. In contrast, LinGO calculates the DFD by means of multiple metrics to finds reliable routes, and thus during link validation time, the nodes transmit the video packets with reduced packet loss rate. In specific terms, LinGO reduces the loss of I-frames and P-frames by around 25% compared to BLR and MRR. Thus, we can conclude that LinGO protects the priority frames during congestion and link error periods, which increases the video quality from user's perspective.

D. Impact of Video Motion and Complexity

Current studies classify videos into three categories according to their motion and complexity, namely low, medium and high. Low motion means videos with a small moving region of interest (face) on a static background, e.g. Hall and Highway video sequences. Medium motion includes videos with a continuous change of scene, e.g. Mobile video sequence. High motion covers videos of sports activities [20]. In this section, we describe simulations that transmitted Hall, Mobile and Highway video sequences, and used the parameters of Table I. In this way, we aimed to evaluate the impact of video motion for multimedia dissemination with QoE support *, as shown the results in Figure 8.

Figure 8 shows that the mobile video sequence has a lower video quality than Hall and Highway. This is because Mobile video includes contiguous scene modification and a wide-angled camera, i.e. high motion and complexity. This produces a video with larger frames and greater difference in size between P- and B-Frames. On the other hand, Hall and Highway video sequences have a small moving region of interest on a static background. Hence, they lead to a low motion/complexity and smaller difference in size between the P- and B-Frames. For these reasons, videos with high spatial complexity (i.e. Mobile video sequence) produce larger I-frames, which are fragmented into several packets. Thus, the dropping probability of an I-frame increases, which produces a different impact on the video quality level.

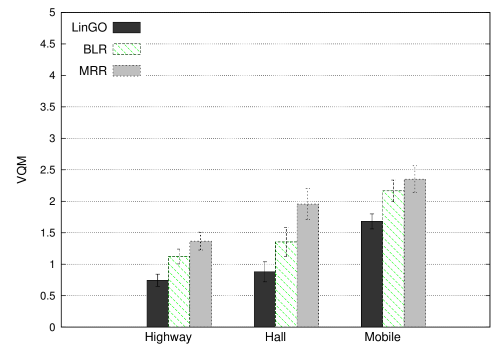


Fig. 8. Impact of Video Motion and Complexity

LinGO also outperforms BLR and MRR in these three scenarios that involve videos with different motion. This can be explained by the fact that LinGO relies on multiple metrics to find reliable routes, which protects the frames of congestion and link error periods. In specific terms, LinGO reduces loss of I- and B-frames by around 15% compared with BLR and MRR for Hall, Highway, and Mobile video sequences.

In our subjective evaluation, 25 observers evaluated the videos, which included undergraduate students, postgraduate students and university staff. They had normal vision, and their age ranged from 18 to 45 years old. The evaluations were conducted using a Desktop PC Intel Core i5, 4GB RAM and a 21" LCD monitor. We implemented a software to play the videos in random order at the center of the monitor against a neutral gray background, as well as to collect observer scores as recommended by ITU.

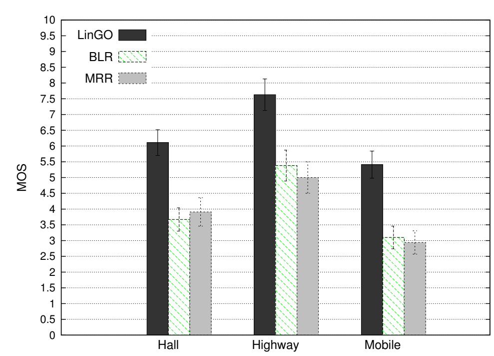


Fig. 9. Subjective Evaluation per video sequence

By analysing MOS evaluations in Figure 9, we conclude that LinGO increases the video quality from the human's experience by around 50% in relation to BLR and MRR, even though the topology is continuously changing. Due to the loss of an I-frame, the video quality only recovers when the decoder receives an unimpaired I-frame. BLR and MRR have a higher packet loss for I-frame than LinGO, reducing the video quality from user's experience for a certain unit of time. This is not desirable for mobile multimedia IoT applications. As LinGO selects reliable routes based on multiple metrics, it protects priority frames of congestion/link error periods.

*We selected a set of transmitted videos via LinGO, BLR, and MRR to make available for download at http://cds.unibe.ch/research/M3WSN/

V. Conclusion

This article introduced LinGO, a protocol to enable video dissemination with QoE support in mobile multimedia IoT applications. LinGO targets the delivery of video with QoE assurance to support wireless sensor-based multimedia networks to feed smart cities/IoT platforms. LinGO enables the finding of reliable routes for transmitting multimedia content with a minimum video quality from a user's perspective. The protocol adopts a DFD-based approach, and takes into account multiple metrics, such as link quality, progress, and remaining energy.

Simulation results highlighted the benefits of LinGO by measuring SSIM, VQM, and MOS metrics. LinGO provides a VQM gain by around 30% compared to BLR and MRR in scenarios composed of mobile nodes with different speeds and transmitting videos under different motion and complexity. This is achieved due to the cross-layer multiple metrics that progress together with link reliability.

References

[1] L. Zhou and H.-C. Chao, "Multimedia traffic security architecture for the internet of things," *IEEE Network*, vol. 25, no. 3, pp. 35–40, 2011.

[2] S. Ickin, K. Wac, M. Fiedler, L. Janowski, J.-H. Hong, and A. Dey, "Factors influencing quality of experience of commonly used mobile applications," *IEEE Communications Magazine*, vol. 50, no. 4, pp. 48–56, apr. 2012.

[3] E. Macias, J. Lloret, A. Suarez, and M. Garcia, "Architecture and protocol of a semantic system designed for video tagging with sensor data in mobile devices," *Sensors*, vol. 12, no. 2, pp. 2062–2087, 2012.

[4] A. Shaw and K. Mohseni, "A fluid dynamic based coordination of a wireless sensor network of unmanned aerial vehicles: 3-d simulation and wireless communication characterization," *IEEE Sensors Journal*, vol. 11, no. 3, pp. 722–736, 2011.

[5] Y. Li, B. Weng, Q. Liu, L. Tang, and M. Daneshmand, "Multiple ferry routing for the opportunistic networks," in *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM 2011)*. IEEE, 2011, pp. 1–5.

[6] C.-J. Hsu, H.-I. Liu, and W. K. G. Seah, "Survey paper: Opportunistic routing - a review and the challenges ahead," *Computer Network*, vol. 55, no. 15, pp. 3592–3603, oct. 2011.

[7] T. Braun, M. Heissenbüttel, and T. Roth, "Performance of the beaconless routing protocol in realistic scenarios," *Ad Hoc Network*, vol. 8, no. 1, pp. 96–107, jan. 2010.

[8] N. Baccour, A. Koubâa, M. Jamâa, D. Rosário, H. Youssef, M. Alves, and L. Becker, "RadiaLE: a framework for designing and assessing link quality estimators," *Ad Hoc Networks*, vol. 9, no. 7, pp. 1165–1185, 2011.

[9] S. Biswas and R. Morris, "ExOR: opportunistic multi-hop routing for wireless networks," *ACM SIGCOMM Computer Communication Review*, vol. 35, no. 4, pp. 133–144, Aug. 2005.

[10] X. Mao, S. Tang, X. Xu, X. Li, and H. Ma, "Energy-efficient opportunistic routing in wireless sensor networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 11, pp. 1934–1942, 2011.

[11] X. Yang, J. Yin, and S. Yuan, "Location-aided opportunistic routing for mobile ad hoc networks," in *Proceedings of the 5th International Conference on Wireless Communications, Networking and Mobile Computing*. IEEE, Sep. 2009, pp. 1–5.

[12] S. Yang, C. K. Yeo, and B. S. Lee, "Robust geographic routing with virtual destination based void handling for manets," in *Proceedings of the IEEE 71st Vehicular Technology Conference*. IEEE, May 2010, pp. 1–5.

[13] M. Al-Otaibi, H. Soliman, and J. Zheng, "A multipath routeless routing protocol with an efficient location update mechanism," *International Journal of Internet Protocol Technology*, vol. 6, no. 1/2, pp. 75– 82, 2011.

[14] M. Lu, P. Steenkiste, and T. Chen, "Video transmission over wireless multihop networks using opportunistic routing," in *Packet Video 2007*. IEEE, 2007, pp. 52–61.

[15] H. Seferoglu and A. Markopoulou, "Video-aware opportunistic network coding over wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 5, pp. 713–728, june 2009.

[16] K. Srinivasan, P. Dutta, A. Tavakoli, and P. Levis, "An empirical study of low-power wireless," *ACM Transactions on Sensor Networks*, vol. 6, no. 2, pp. 1–49, Mar. 2010.

[17] G. Zhou, J. A. Stankovic, and S. H. Son, "Crowded spectrum in wireless sensor networks," in *Proceedings of 3th Workshop on Embedded Networked Sensors (EmNets)*, 2006.

[18] G. Chen, K. Itoh, and T. Sato, "Enhancement of beaconless location-based routing with signal strength assistance for ad-hoc networks," *IEICE transactions on communications*, vol. 91, no. 7, pp. 2265–2271, 2008.

[19] Z. Zhao, T. I. Braun, D. Rosário, E. Cerqueira, R. Immich, and M. Curado, "QoE-aware FEC mechanism for intrusion detection in multi-tier wireless multimedia sensor networks," in *Proceedings of the 1st International Workshop on Wireless Multimedia Sensor Networks (WiMob'12 WS-WMSN)*, Barcelona, Spain, oct. 2012, pp. 697–704.

[20] E. Aguiar, A. Riker, A. Abelém, E. Cerqueira, and M. Mu, "Video quality estimator for wireless mesh networks," in *20th International Workshop on Quality of Service (IWQoS)*. IEEE, 2012, pp. 1–9.

Denis Rosário received Master's Degree in Automation and Systems Engineering by the Federal University of Santa Catarina, Brazil. Since 2010, he has been doing a Ph.D. in Electrical Engineering at the Federal University of Para, Brazil, and currently, he is an exchange student at the Institute of Computer Science and Applied Mathematics, University of Bern, Switzerland. His current research interests include the following: Internet of Things, Mobility, Quality of Experience, and Routing Protocols.

Zhongliang Zhao got his M.Sc degree in Telecommunicatio network from Politecnico di Torino, Italy, in 2008. From end of 2009, he has been a PhD student and research assistant at the Institute of Computer Science and Applied Mathematics of University of Bern, Switzerland. His research interests include opportunistic routing, topology control, and mobility management in mobile ad hoc networks.

Eduardo Cerqueira received his PhD in Informatics Engineering from the University of Coimbra, Portugal, in 2008. He is an associate professor at the Faculty of Computer Engineering of the UFPA in Brazil. His publications include four books, four patents and over than 60 papers in national/international refereed journals/conferences. His research involves multimedia, Future network, Quality of Experience, and Mobility.

Torsten Braun got his diploma and Ph.D. degrees from the University of Karlsruhe, Germany, in 1990 and 1993, respectively. Since 1998 he has been a full professor of computer science at the Institute of Computer Science and Applied Mathematics (IAM) of the University of Bern (Switzerland), heading the Computer Networks and Distributed Systems research group. His research interests include QoE, wireless networks, mobility and multimedia.

Aldri Santos is a researcher and professor at the Federal University of Paraná, in the Department of Informatics. He received his Ph.D. in Computer Science from Department of Computer Science of the Federal University of Minas Gerais, Belo Horizonte, Brazil. Aldri received both his M.Sc. and B.Sc in Informatics from Federal University of Paraná, Curitiba, Brazil. From July to October 2001 he was an invited researcher at Cyber Solutions Inc., Sendai, Japan. He also is member of the SBC (Brazilian Computing Society).