Optimized Path Selection in a Game-Theoretic Routing Protocol for Video-Streaming Services over MANETs

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***Abstract*—Mobile ad hoc networks (MANETs) are infrastructureless networks formed by wireless mobile devices. Recently, the demand over multimedia services such as video streaming has increased specially since the number of mobile end users is growing as well. MPEG-2 VBR is one of the most fitting video coding techniques for MANETs which improves the distribution of video streams specially when it is used with a proper multipath routing scheme. In this article, we aimed to design a routing scheme to dynamically select the forwarding paths using a game-theoretic approach over a multipath routing protocol. Our proposal seeks to describe an equation of the probability p of sending video frames through the best available path. p depends on network parameters that vary throughout time. The aim is that the most important video frames (I+P) will be sent through the best path with a certain probability p and will be sent through the second best path with a probability $1-p$. To achieve that, we carried out simulations done with fixed values of p and after that we applied a lineal regression method to obtain the coefficients of the equation for p. Simulations have been done to show the benefits of our proposal where interfering traffic and mobility of the nodes are present.**

***Keywords*—Mobile ad hoc networks, adaptive multipath routing, game theory, video-streaming services.**

I. INTRODUCTION

A Mobile Ad hoc NETwok (MANET) is a group of wireless mobile nodes (MNs) able to communicate with each other. MANETs are self-organized networks that operate without the need of any fixed network infrastructure or centralized administrative support. MANETs suffer from link breakages and frequent changes of network topology due to nodes that move and have a limited battery life. In addition, the transmission range in such mobile devices is limited, so each node will operate both as a terminal host and as a forwarding node. MANETs should adapt dynamically to be able to maintain communications despite all these issues [1].

MANETs have attracted much attention from the research community over the last years and important technical advances have risen. Recently, these multi-hop networks are considered as an important kind of next generation network access, where multimedia services will be demanded by end users. Two main reasons seem to ensure the success of these networks: firstly, the increasing number of multimedia devices capable of maintaining wireless communications; secondly, the growing number of users who require these multimedia services from their mobile devices. Nowadays, video-streaming services are demanded by users using their mobile terminals from everywhere. In many situations and areas, these demanding users may spontaneously form an infrastructureless ad hoc network to share their resources and their contents.

Multimedia services require Quality of Service (QoS) provision. The special characteristics of MANETs, such as mobility, dynamic network topology, energy constraints, infrastructureless and variable link capacity, make the QoS provision over these networks an important target. That is, instead of using fixed network configuration parameters, a better solution is to adjust the framework according to current environmental parameters.

Our research focuses on the design of a QoS-aware self-configured dynamic framework able to offer video-streaming services over MANETs. In this work, we aimed to design a dynamic selection of the forwarding paths using a game-theoretic approach plus a multipath multimedia routing protocol (MMDSR). This contribution seeks to further enhance the overall performance of the service.

The rest of the paper is structured as follows. Section II presents the basics of our framework. In section III we explain the features of our multipath routing protocol. Section IV gives a brief explanation of the game-theoretic proposal. Simulation results are shown and analyzed in section V. Finally, conclusion and future work are given in section VI.

II. BASICS OF THE FRAMEWORK

We used a framework which provides video-streaming services over IEEE 802.11e [8] MANETs. The multipath routing scheme used in this work is based on the DSR (Dynamic Source Routing) protocol [9]. Video is distributed using RTP/RTCP (Real-time Transport Protocol/RTP Control Protocol) [10] over UDP as a transport protocol. Next, we will summarize the main ideas of the video coding and the IEEE 802.11e standard that we used in our framework.

Our system uses a layered MPEG-2 VBR coding of the video flow, which is formed by sets of frames, usually 4 to 20 frames, called GoP (Groups of Pictures). A GoP has three types of frames: I, P and B, and has a unique frame-pattern in a video repeated in each GoP. I (Intra) frames encode spatial redundancy. They are the base layer and provide a basic video quality. They carry the most important information for the

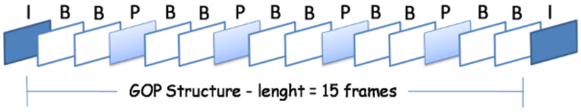


Fig. 1. MPEG-2 GoP structure.

decoding process at the receiving side. The whole GoP would be lost if the corresponding I frame were not available at decoding time. P (Predicted) and B (Bi-directional) frames carry differential information from preceding (for P) or preceding and posterior (for B) frames, respectively. Considering these characteristics, different priorities could be assigned to the video frames according to their importance within the video flow. Therefore, I frames should have the highest priority, P frames a medium one and B frames the lowest one. The structure of a GoP is shown in figure 1, where we can see the relationship between frames at decoding time.

In the MAC (Media Access Control) layer, we used the IEEE 802.11e [8] standard, which provides QoS support to services such as video-streaming. It consists of four different Access Categories (AC). Each packet from the higher layer arrives at the MAC layer with a specific priority value and it is mapped into the proper AC. We defined the mapping of the different packets into each one of the four access categories of the IEEE 802.11e MAC as follows:

- AC0: signaling.
- AC1: high priority packets (I frames).
- AC2: medium priority packets (P frames).
- AC3: low priority packets (B frames + other best effort traffic).

III. Multipath Multimedia Dynamic Source Routing (MMDSR)

In this section we will give a brief summary of the main features of the framework, whose complete description was presented in [2], [3]. In those previous works we presented the MMDSR routing protocol, which here is just summarized very briefly. In this present article we further improve the game-theoretical routing scheme by designing an equation for p that depends on some network parameters. This way, the framework is able to dynamically adapt to the changing network conditions inherent in MANETs.

A. Multipath routing scheme

MMDSR is a multipath routing protocol that uses the standard DSR as base to search for available paths. MMDSR uses up to three paths where the three types of video frames will be sent. As figure 2 shows, the most important video frames (I frames) should be sent through the best path available; P frames through the second best path (medium path) and B frames through the third (worst one). Nonetheless, a different way to send I, P and B frames could be used. In both [5] and [6], they proved that arranging more than three paths simultaneously in a multipath scheme will not give a big improvement benefit while an increasing excessive overhead will be detected .

The user requirements are considered using QoS parameters knowing their threshold values to provide the negotiated image quality. We use the following parameters: minimum

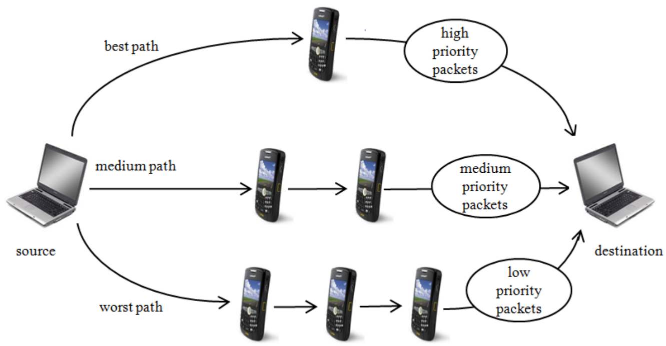


Fig. 2. Multipath routing scheme using three paths.

expected bandwidth (BW_{min}), the maximum percentage of data losses (L_{max}), the maximum delay (D_{max}) and the maximum delay jitter (J_{max})

$$customer\_req \equiv \{BW_{min}, L_{max}, D_{max}, J_{max}\} \quad (1)$$

B. MMDSR control packets

All decisions such as the path selection or the tunning of configuration parameters are operated from the source.

MMDSR periodically discovers *D* available paths between source and destination by sending monitoring *Probe Message* (PM) packets. After that, a *Probe Message Reply* (PMR) packet is generated at destination to carry the collected information about the quality of the available paths. Notice that the reduced size of theses packets and the low frequency of sending them makes the incurred overhead almost negligible. Figure 3 shows the PM and PMR packets which are periodically interchanged between source and destination.

Finally, a score is given to each one of the paths after analyzing the feedback information at the source node, which classifies them accordingly. Actually, the quality parameters of the paths will be compared to certain thresholds and then the source selects three paths to compose the multipath scheme. The details of the score process can be seen in [2]. *path-state* is a vector that has all quality parameters calculated for each one of the available paths:

$$path-state^i_k \equiv \{BW, L, D, J, H, RM, MM\}^i_k \quad (2)$$

where *i* is the iteration number of the algorithm and *k* refers to each one of the paths (with $k \leq D$). The other parameters are: end-to-end available bandwidth (BW^i_k), percentage of losses (L^i_k), delay (D^i_k), delay jitter (J^i_k), hop distance (H^i_k), reliability Metric (RM^i_k) calculated from the SNR (Signal to Noise Ratio) of the links involved in each path, and Mobility Metric MM^i_k calculated from the relative mobility of the neighboring nodes within each path.

To refresh the paths, this process is repeated periodically due to the topology of MANETs that vary and can produce link breakages. This routing period depends on the network state, as it is shown in section III-D.

C. Path classification

Once we have selected a set of paths that fulfil the requirements (see equation (1)), the classification of those paths is done by checking sequentially the qualifications of the QoS parameters as seen in the following list:

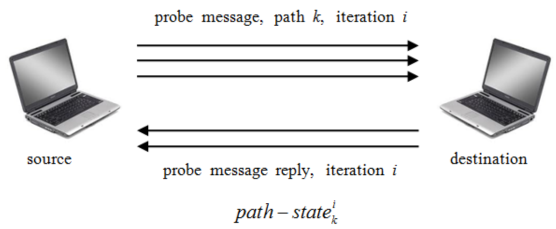


Fig. 3. PM and PMR packets.

1) $RM_k^i + MM_k^i$
2) H_k^i
3) BW_k^i
4) $L_k^i + J_k^i$
5) D_k^i.

First of all, the two metrics RM and MM are used to classify paths since the most reliable and stable paths should be a priority for the correct distribution of video-streaming services over MANETs. In case of draw, the decision is taken depending on the hopcount metric which decide the shortest path. In case of another draw, we consider bandwidth, losses, delay jitter and delay to break the draw, knowing that they are not so decisive metrics in such scenarios. Finally, the source selects k paths (with $k \leq D$) required to compose the multipath routing scheme. In our case, k=3 paths. Notice that if only two paths were available, we still could differentiate both paths (i.e., the better and the worst), but if only one was available then all the packets would be sent through that single path.

D. MANET self-configuration

Here, we will just point out the basics of the self-configuration operation. For further details please see [2], [3]. Due to the network topology of MANETs which is highly variable, any proposed solution should be dynamic. Having this in mind, we designed a self-configured proposal named a-MMDSR (adaptive-MMDSR) [2], [3].

Our framework monitors the current state of the network and in case of changes, the algorithm modifies some configuration parameters, e.g. the routing period of the algorithm and the thresholds to classify paths. We apply some tuning functions to adjust those parameters dynamically depending on a new parameter called *NState*, which has information about the global network state and is updated by the algorithm iteration by iteration. *NState* is computed as follows

$$\begin{aligned} NState^i \;=\; & w_{RM} \cdot \overline{RM^i} + w_{MM} \cdot \overline{MM^i} + \\ & w_{BW} \cdot \overline{BW^i} + w_L \cdot \overline{L^i} + \\ & w_D \cdot \overline{D^i} + w_J \cdot \overline{J^i} + w_H \cdot \overline{H^i}. \end{aligned} \quad (3)$$

In equation (3) upper bars denote averages and the *w*s are appropriate weights that sum one. When the source receives the feedback from the network by means of PMR packets, it calculates the *NState* using equation (3).

As *NState*, the routing period ($T_{routing}$) to refresh the multipah scheme also varies dynamically and is calculated according to

$$T_{routing}^{i+1} = 10 \cdot NState^i + 3. \quad (4)$$

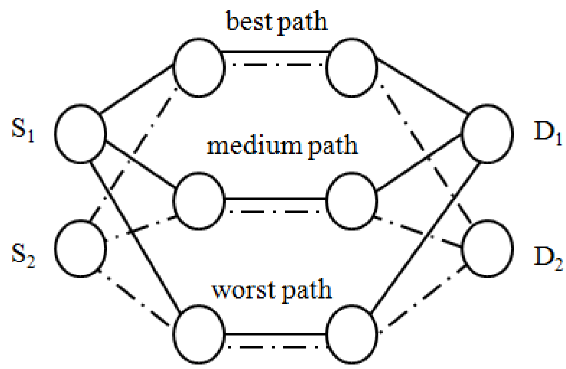


Fig. 4. Fixed strategy to allocate resources.

To reach to the previous equation, a high number of simulations were conducted under a wide range of situations where the network performance was good, normal and bad. The goal was to make it lineal (simple) because it will be computed by light mobile devices.

Till now, we have presented the basics of a QoS-aware adaptive multipath routing protocol. Next, we introduce a game-theoretic routing scheme to further improve the performance of video streaming services over MANETs.

IV. Game Theory in MANETs

Game theory is a branch of applied mathematics that has been used basically in economics to model competition between companies. During the last years, game theory has also been applied to networking, generally to solve routing and resource allocation problems in a competitive environment. MANET nodes make decentralized decisions, and resource management mechanisms can help these nodes to behave in such a way that is constructive to the network as a whole [11]. We applied Game Theory in our multipath routing protocol to develop the present proposal. Each source node has a set of video frames (I, P and B) of a video flow to be transported and has three paths through which those frames could be sent. Nodes *play* a *routing game* to distribute the video flows trying to reach their own best performance. The *players* of the game are the MANET nodes and the *action* of the game is to select the proper route to forward their video-streams. In the following section, we will introduce the game-theoretic proposal included in the multipath routing scheme.

A. A game-theoretic routing protocol

Figure 4 shows the proposed architecture. A complete description of the framework can be found in a previous work [4]. For simplicity of comprehension, we assume two connections (S_1-D_1, S_2-D_2) and three paths. However, it is possible to apply this proposed architecture to any MANET independently from the number of connections, nodes and paths.

By default, nodes always try to send the most important video frames through the best available path discovered by the multipath routing protocol. This means that I frames, which are the bigger ones, will be sent through the best path, whereas the least important frames (i.e., B frames) will be sent through the worst one. Nevertheless, if each node prefers to send the

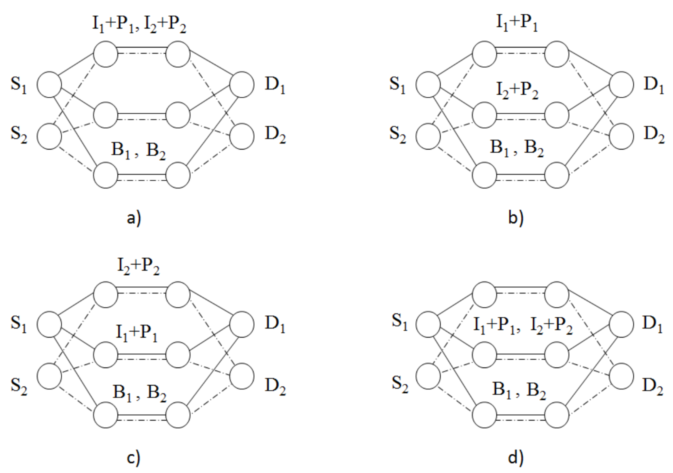


Fig. 5. Four possible allocation situations after playing the game.

most important frames through the best path, this path could got congested. As a consequence, that best path could suffer more losses than the others, which would lead to classify it as a worse path. This behavior could provoke an oscillatory performance that might affect the video experience of users if it happened frequently.

To cope with this issue, users could *play a game* such that the best two paths (best, medium) could be selected by each player to transmit the most important video frames. That is, each user will prefer to send sometimes the most important frames through the second best path. Just for simplicity, B frames are considered always to be sent through the third path, which is the worst one. Also, I and P frames belonging to the same video stream are going to be sent through the same path to make more evident the inconveniences of sharing the same path, since there are more P frames than I frames per flow.

In our game, in each iteration users select paths for their respective video flows. As shown in figure 5, we have four possible situations. I+P frames will be sent through the best path by each user with certain probability p. That is, p is the probability according with users to send their I+P frames through the best available path, where $1 - p$ is the probability that users send their I+P frames through the second best available path. It is important to remember that without playing the game, both users would always send the important frames through the best path (figure 5a). Alternatively, they could play our routing game so that three additional situations would exist as it is depicted in figure 5b, 5c and 5d. In cases b) and c), the user who sends I+P frames through the best path notices a considerable improvement, whereas the other user detects an improvement as well even if it is not so much noticeable. Therefore, cases b) and c) outperform case a). Nonetheless, case d) is worse than a) for both users since they are sending their frames together through the worst path. Notice that players (users) must decide their choices simultaneously and without communicating with each other. A best response; taking other players strategies as given, is a strategy that gives the most favorable outcome for a player. A Nash Equilibrium [7] is a solution where each player plays a best response to the strategies of other players. As an assumption, each player knows the strategies of the other players, and no player will get more benefits to a unilaterally change of their current strategy while the other players keep theirs unchanged.

B. Our new proposal to compute p

Each user plays the routing game to select the forwarding path at each round of the game. So I+P frames are sent through the best path with a certain probability p, which is computed by each source node at each round using equation (5). As we will see, in our approach p is updated over time and it adapts to the changing conditions of the network basically measured in terms of losses. Without the game, I+P frames would always be sent through the best available path (i.e., $p = 1$).

For each video transmission between two nodes, the average packet losses, average end-to-end packet delay and jitter were measured for a different number N of video flows (2 to 5), with and without using our game-theoretic scheme in our MMDSR routing protocol.

The proposal to compute p consists on finding an equation that depends on some network parameters, such as the packet losses and the number of users. This way, the probability p of sending I+P frames through the best path will adapt to the changing networks conditions throughout time. To do this, we conducted a high number of simulations varying the probability p and the number of players (users) N. N varies from 2 till 5 players and p varies from 0.5 till 0.9. In each simulation, we measured the average packet losses as the QoS parameter considered to calculate the coefficients of an equation for p. The equation for p has the following form

$$p(N, Losses) = \beta_0 + \beta_1 \cdot N + \beta_2 \cdot Losses \tag{5}$$

where

- p = Probability of sending (I+P) frames through the best path.
- N = 2, 3..., N_p where N_p is the number of players.
- $Losses$ = Packet losses from source till destination, i.e.

$$Losses = \left(\frac{packets_{sent} - packets_{received}}{packets_{sent}} \right) \cdot 100 \tag{6}$$

- β_0, β_1 and β_2 are constants to be calculated.

It is important to mention that in each *Hello Message* (HM), a new field is added to indicate if the node which sent the HM is a video source sender or not. In this way, each node can know how many video source senders are among its neighbours. Then the node can estimate, assuming homogeneity, the total number of video source senders N in the MANET given that the area is known. Finally, the node will be able to compute the value of p using (5).

V. Simulation Results

Our proposal was implemented in the open source network simulator ns-2 (v2.27) [12] where we conducted simulations to evaluate the benefits of our approach. The MANET scenario was generated with the Bonnmotion tool [13]. Interfering CBR traffic was generated to constrain the paths. The simulation settings of the scenario are shown in table I.

The scenario used to test the proposal consists of a set of 50 motion nodes distributed in a MANET of 520x520 m. The

Table I
SIMULATION SETTINGS SCENARIO.

Area	520x520m
Number of nodes	50
Average node speed	2 m/s
Transmission range	120m
Mobility Pattern	Random Waypoint
MAC specification	IEEE 802.11e, EDCF
Nominal bandwidth	11 Mbps
Simulation time	200s
Video codification	MPEG-2 VBR
Video bit rate	150 Kbps
Video sources	2 to 5
Video	Blade Runner
Routing protocol	Game Theoretic algorithm + MMDSR
Transport protocol	RTP/RTCP/UDP
Maximum packet size	1500 Bytes
Multipath scheme	K=3 paths
Weighting values (equation (3))	1/7
Queue sizes	50 packets
Interfering CBR traffic	300 Kbps
Channel noise	-92 dBm
Mobility generator	Bonnmotion

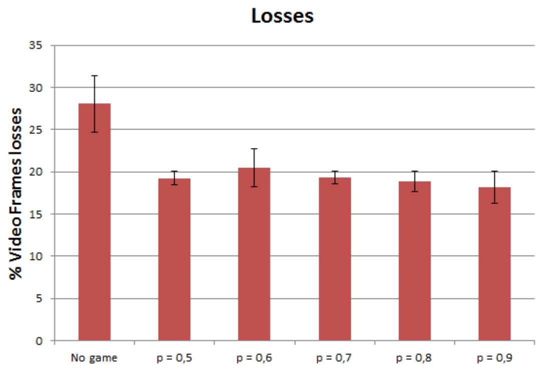
transmission range of the nodes is 120 m. Nodes move with a speed up to 2 m/s. Video flows are transmitted from node S_1 to D_1, S_2 to D_2 till S_N to D_N, where N is the number of players (users). The paths discovered by the MMDSR routing protocol are the same for all sources and are equally classified for all the users using the MMDSR path classification described in section III-C. Each source decides the path to route packets according to the routing game presented in section IV-A and depicted in figure 5.

After multiple simulations, we found the optimal probability p^* that produced lower losses for N= 2, 3, 4 and 5 players. After that, we used lineal regression to obtain the coefficients of the p expression shown in equation (5). The obtained values of the coefficients were: $\beta_0 = 1.2390$, $\beta_1 = -0.1806$ and $\beta_2 = 0.004298$. As the following figures depict, using equation (5) simulations show clear benefits when a variable p is used, compared to the case of using a fixed p value. After we found the values of β_0, β_1 and β_2, we test the results of the output p using (5) by giving the values of losses and N as an inputs. Results of p values are almost the same as shown in table II. This test makes our equation validated.

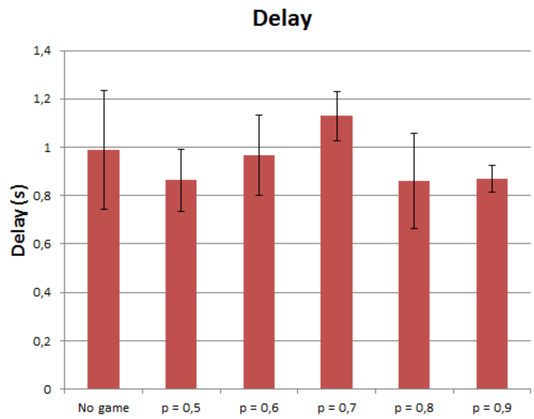
All the figures present confidence intervals (CI) of 90% obtained from five simulation per point. In the following, results of losses, average jitter delay and average end-to-end delay are shown for the case of using the game-theoretic routing versus the case of non using it. We vary the number of users (players) N= 2, 3, 4 and 5. When we use a fixed p, the probability p of choosing the best path to transmit I+P video frames varies from 0.5 till 0.9.

A. For N = 2 players

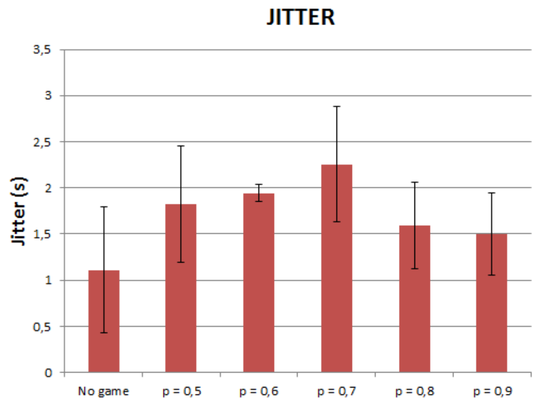
Figure 6(a) shows the average percentage of frame losses when using the game-theoretic scheme for a fixed p value from 0.5 till 0.9 versus the case of non using any game-theoretic scheme (*No game*). We can clearly notice how including the game-theoretic routing scheme, the average video frame losses are reduced from 28% to around 20% depending on the p value. We obtain the lowest value for losses, which is 18,1553% for p^* = 0.9. That is, when 90%



(a) Average packet losses



(b) Average delay

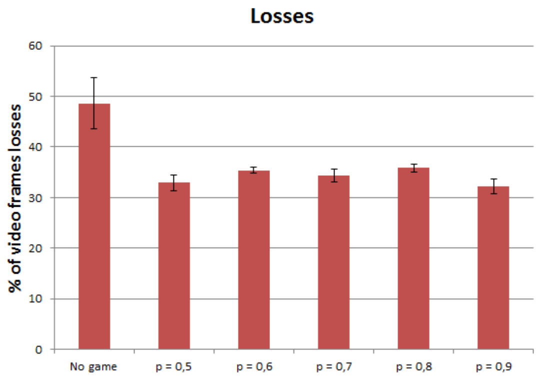


(c) Average delay jitter

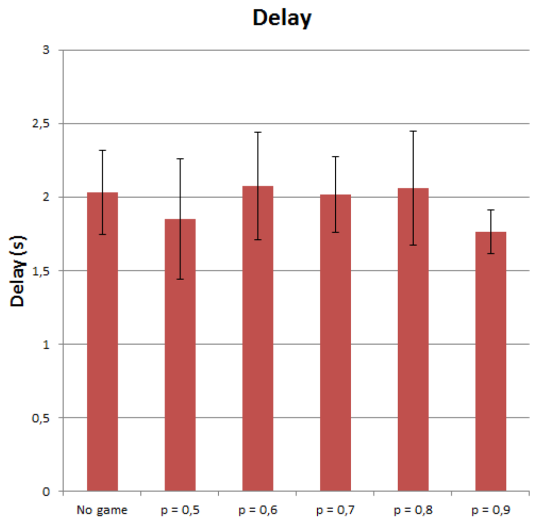
Fig. 6. Losses, delay and jitter delay for N = 2 players

of the time users choose the best path to transmit I+P video frames and 10% of the time they choose the worst path. Notice that without using the game-theoretic approach losses were 28%. This result is due to our routing game that spreads the load among the two best paths so that network resources are used more efficiently and losses decrease.

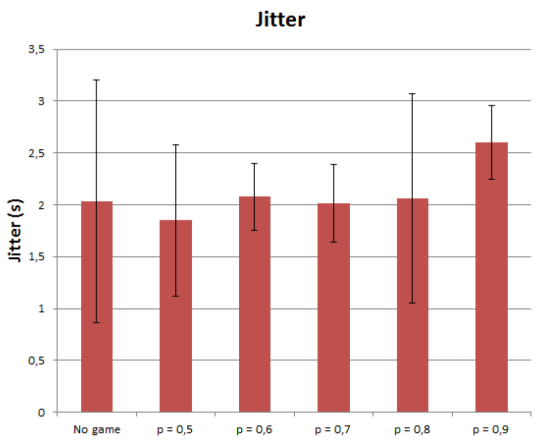
Figure 6(b) shows the average end-to-end packet delay. We see that the delay using the game-theoretic scheme for p = 0.8 or 0.9 shows a better value compared to the *No game* case. Figure 6(c) shows the average delay jitter suffered by the packets. The jitter using the game-theoretic scheme does not show a better result unless for p^* = 0.9, which has a slightly higher value than for the *No game* case.



(a) Average packet losses



(b) Average delay



(c) Average delay jitter

Fig. 7. Losses, delay and jitter delay for N = 3 players

In a previous work [4] we presented a 2-player game-theoretical routing scheme for MANETs where we obtained p^* analytically, although only for the case $N = 2$ players. Our goal as future work is to develop a general game-theoretical routing model for any number of players N. Basically, the MOS (Mean Opinion Score) in each available path was estimated from the packet losses reported in RTP packets using equation (7). Then, the optimum p^* was computed applying equations (7) and (8) in (9). Please, refer [4] to see the whole explanation of the proposal. From figure 6(a) for $N = 2$ we see that the optimum p value is $p^* = 0.9$, whereas in [4] it was $p^* = 0.75$. The reason is that in [4], the average MOS in the best path and in the second best path were $\mu_1 = 4$, $\mu_2 = 2$, respectively. Here, in our scenario these averaged values were $\mu_1 = 5$ and $\mu_2 = 1$. Substituting the MOS values in equation (8) and (9), we obtain $A(\mu_1, \mu_2) = 2$ and p^*=0.75 in [4] and $A(\mu_1, \mu_2) = 1.2$ and $p^* = 0.9$ in this present work. Notice that $p^* = 0.9$ is the same value obtained in our experiments. This comparison leads to the conclusion that depending on the network characteristics we can get one or another optimal p^*.

$$MOS_i = \mu_i \simeq \lfloor 5 \cdot e^{-12 \cdot Losses_i} \rfloor \tag{7}$$

$$A(\mu_1, \mu_2) = 1 + 4 \cdot \frac{\mu_2}{(\mu_1 - \mu_2) \cdot \mu_1} \tag{8}$$

$$p^* = \frac{1}{2}\left(1 + \frac{1}{A(\mu_1, \mu_2)}\right), 0.5 \leq \{p^*\} < 1 \tag{9}$$

B. For N = 3 players

Figure 7(a) shows the average percentage of video frame losses with and without including the proposed routing game.

Again, we notice how including the game-theoretic routing scheme, the average video frame losses are reduced. We obtain the best value for losses with p^* = 0.9. Figure 7(b) shows the average end-to-end delay with and without the game-theoretic scheme. The game-theoretic scheme for p^* = 0.9 shows the lowest delay. Figure 7(c) shows the delay jitter, which is between 2 and 2.5 sec.

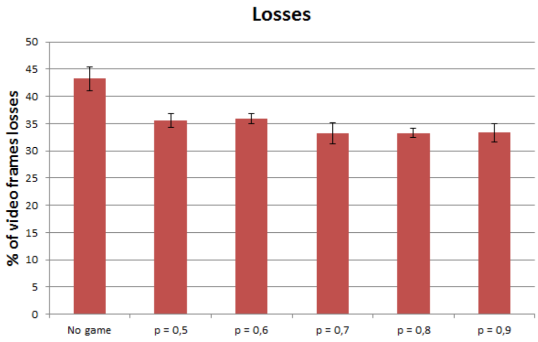
C. For N = 4 players

Figure 8(a) shows the average percentage of video frame losses with and without the proposed routing game. Here, we obtain the lowest value for losses with p^* = 0.7. Figure 8(b) depicts the average end-to-end packet delay. In this case, delay values do not vary a lot, showing values from 0.8 sec to 1.2 sec. Figure 8(c) represents the delay jitter. In this case, we see how the jitter is better when p is greater than 0.5, reaching negligible values.

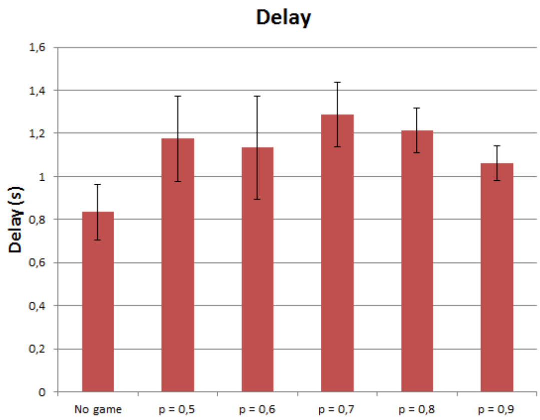
D. For N = 5 players

Figure 9(a) shows the average percentage of video frame losses with and without including the proposed routing game. Again, including the game-theoretic routing scheme, the average video frame losses decrease. We obtain the lowest value for losses with p^* = 0.5. Figure 9(b) shows the average end-to-end delay. We obtain the best value for p^* = 0.5 too. Figure 9(c) shows the delay jitter. In this case, we obtain the best value for p^* = 0.5 as well.

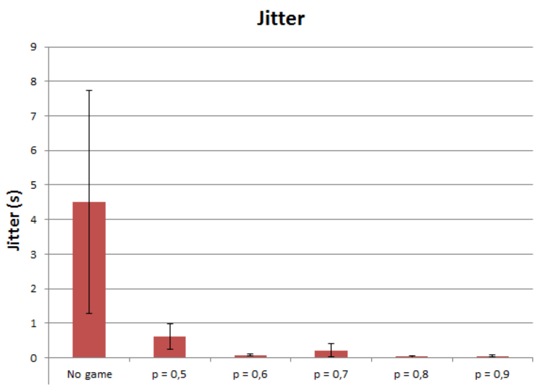
After seeing the previous results, we can see that for $N = 2$ and $N = 3$ players, the optimal value of p that offers the lowest losses is $p^* = 0.9$. For $N = 4$, we obtain $p^* = 0.7$ and for $N = 5$ the optimal value of p is $p^* = 0.5$. These results are resumed in table II. We can see that as the number of players N increases, the optimal value for p decreases tending to 0.5. This has sense, because as N grows, the traffic increases and the paths get loaded, so the best strategy is to choose



(a) Average packet losses

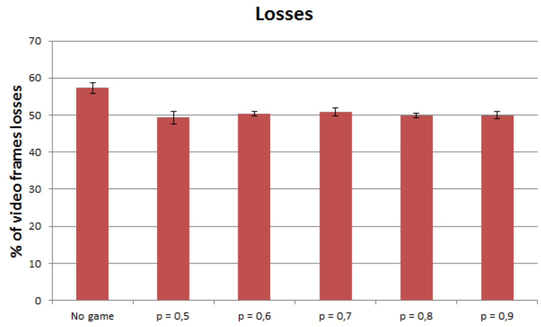


(b) Average delay

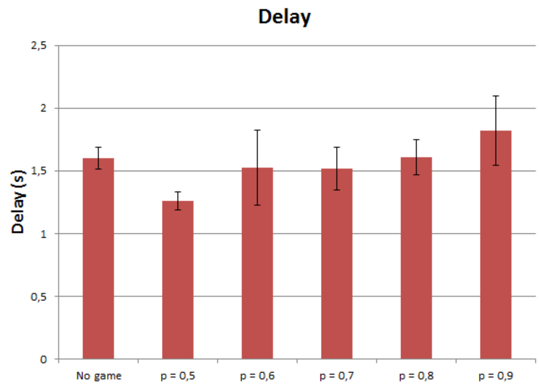


(c) Average delay jitter

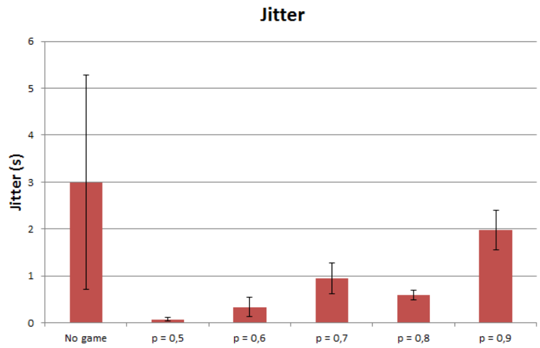
Fig. 8. Losses, delay and jitter delay for N = 4 players



(a) Average packet losses



(b) Average delay



(c) Average delay jitter

Fig. 9. Losses, delay and jitter delay for N = 5 players

Table II
RESULTS OF THE OPTIMAL $p*$ VALUE.

N	% Losses	Optimal p^*
2	18.1553	0.9
3	32.2535	0.9
4	33.2469	0.7
5	49.3450	0.5

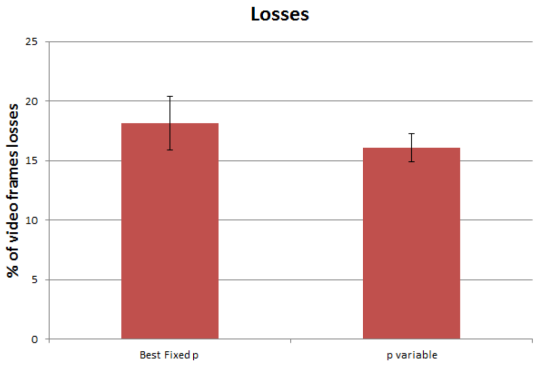
them quite randomly. The load balancing produced by the game-theoretic routing scheme alleviates packet losses. From these results we applied a lineal regression and found the coefficients needed in equation (5).

Now, we will show a performance evaluation obtained with our game-theoretic routing scheme but applying equation (5) to compute p dynamically throughout time instead of using a fixed p value (in particular, the optimal p^*). We will see the results in the scenario for $N = 2$ players.

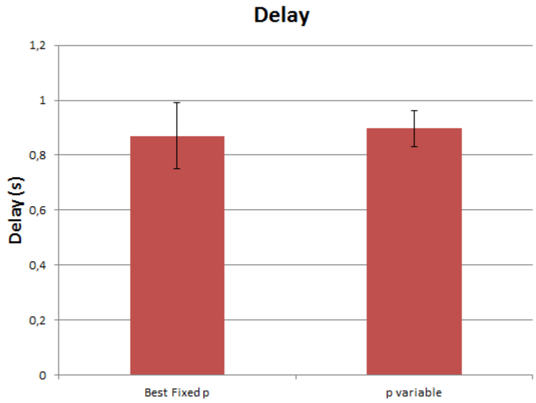
As we can clearly see in figure 10(a), using the variable p losses are lower in comparison to using the best optimal fixed value $p*$. Using our equation for p the probability of choosing the best path to transmit I+P frames depends on the instantaneous characteristics of the network which produces a better behavior.

Figure 10(b) shows the delay which is almost the same in both cases, while the jitter delay shown in figure 10(c) using our new equation to compute p gets a better result.

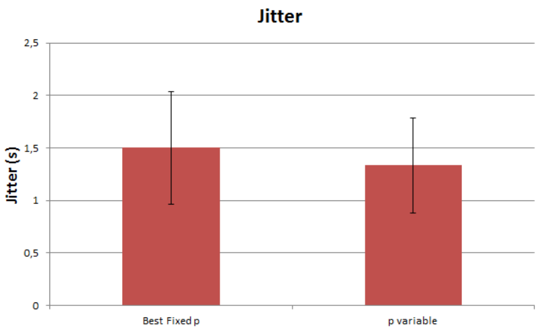
Our multipath routing protocol MMDSR plus our game-theoretic scheme have shown how the global benefits of the users improve if the framework adapts dynamically to the changing network conditions. Our game-theoretical scheme produces lower video frame losses and thus a higher received



(a) Average packet losses



(b) Average delay



(c) Average delay jitter

Fig. 10. Performance for $N = 2$ players, with fixed p^* vs. variable p

video quality. In addition, the network resources are used more efficiently.

VI. Conclusions and Future Work

The inherent dynamic features of MANETs makes providing video-streaming services over wireless mobile ad hoc networks a difficult task. In this paper we have derived from diverse simulations an equation which makes the probability p of sending the most important video frames (i.e., I+P) through the best available path vary depending on some network characteristics. This means, instead of sending I+P video frames always through the best available path, users play a strategic routing game where these frames will be sent through one of the two best paths according to a certain probability p. First, we found by simulation the optimal probabilities p^* which produce the best result. After that, we applied a lineal regression to find the coefficients of the proposed equation (5).

Simulation results show the benefits of our proposal, first outperforming the results compared to the case of non using our game-theoretical routing; and second improving the case of using the game-theoretical routing with a variable value of p over the case of using the fixed value of p^*. Our proposal makes the network more efficient as well as achieves a higher degree of satisfaction of the users.

As a future work, we are planning to develop an analytical approach to compute p in the game-theoretical routing for a general number N of players. In a previous work [4] we solved this for $N = 2$ users, based on a 2-player routing game. Now, we plan to design a N-player routing game. Also, we would like to implement this framework in vehicular ad hoc networks (VANETs), where video-streaming services are taking an important attention. Our proposal could be a solution to improve the routing operation for multimedia data over VANETs.

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