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The Challenge of On-demand Routing Protocols Improvement in Mobility Context

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Abstract—**Mobile Ad hoc NETworks are characterized by rapid change in their topology and the lossy nature of wireless links. In this context, achieving respect the QoS constraints of multimedia communications is a real challenge. Routing protocols play an important role in achieving the required performance. They should be smart enough to select better paths for data transmissions. Several routing approaches are used. Most are derived from adapting those used in wired networks. They are not suited to the context of wireless networks. We focus on the well-known Ad-hoc On-demand Distance Vector (AODV) protocol, commonly used protocol in ad hoc network. Standard route discovery process used in AODV is expected to obtain the best path in term of delay. However, in lossy-links context, multimedia data packet transmission success, on path established thanks to control packets, may require several attempts. These retransmissions increase delay and overhead. Many QoS-based methods failed to make a meaningful improvement due to added complexity and additional delay and overhead. In this paper, we use a convenient and practical way to evaluate quality of links in mobile context. With these measures relating to the number of retransmissions, we produce a new metric. Thereafter, we use this metric to highlight the limitations of QoS approaches used to improve the performance of AODV. We show that improving performance of on-demand routing protocols, in the mobility context, lies on effective control of node neighborhood.**

Keywords–mobility; reliability; wireless networks; quality of service; on-demand routing.

I. INTRODUCTION

In the socio-economic context marked by the need to communicate any time and any where, use of Mobile Ad hoc NETworks (MANET) in the communication chain is essential. However, to communicate in these networks with a satisfactory level of Quality of Service (QoS) stands as a challenge to network services and infrastructures developers. Due to the unstable nature of radio links, routing protocols that establish communication path, are struggling to find and to maintain the best paths between a source and a destination. Indeed, due to the mobility of nodes, obstacles in the medium of the radio wave propagation and interference, the radio links are broken quickly.

In order to guarantee QoS, routing protocols should be smart enough to choose a reliable route in order to avoid packet loss. To deal with the problem, Qos-based routing protocols are proposed. Route selection process should take into account link quality. However, most methods proposed for link quality estimation and best path selection are not appropriate for this rapid topology change. Most QoS protocols have many problems, among which, we can mention the additional costs induced by the determination of the value of the metric used, the accuracy of the value of the metric used, the additional complexity made to the route selection process. The obtained path is, very often, longer than the shortest path (in terms of number of hops). In mobility context, long paths are more vulnerable to breakage than shortest paths. In [1], a primary study was conducted on these issues.

In this paper, we use a realistic simulation environment to explain the problem. We use of a convenient and pratical way to evaluate quality of links in mobile context. Then, we design different QoS-based Ad-hoc On-demand Distance Vector (AODV) protocols. The QoS metric used (called PR-metric) is based on the number of retransmissions. It takes into account accurately the proportion of retransmission time with respect to time of first issue. We use this metric to compare effectiveness of different QoS-based methods used to improve on-demand routing protocols performance. Finally, we conduct a detailed analysis of differend QoS-based AODV protocol performance.

The remainder of the paper is organized as follows: In Section II, we present and analyze related work. In Section III, we present our QoS-based routing protocols. Performance evaluation and discussions are made in Section IV. We conclude in Section V.

II. RELATED WORK AND ANALYZES

In MANET [2], achieving good Quality of Service (QoS) is a critical issue and is very difficult to guarantee mainly due to the dynamic nature of the network and the lossy nature of wireless links. In this context, routing protocols play a significant role. The main goal of any ad-hoc network routing protocol is to establish an efficient route between any two nodes with minimum routing overhead and bandwidth consumption. The protocols are different in terms of routing methodologies and the information used to make routing decisions [3]. The different routing approaches used in MANET can be classified into table driven protocols [4][5] and on-demand protocols [6][7][8]. Table driven protocols are proactive. In the proactive approach, the nodes maintain updated routing tables. To communicate, a path is immediately available for the source node. The drawback of this approach is that control messages are broadcasted periodically in the network. This leads to high routing overhead, limiting the network data communication capabilities. On-demand approaches are source-initiated reactive mechanisms. With this routing approach, a path is issued at the request of the source node. In this study, we focus on reactive protocols. AODV is a well known protocol in this category. In recent years, much effort has been made to improve the standard AODV protocol [6]. In this section, after presenting the critical behaviors of the protocol, we review various proposed improvements. We conclude the section with a discussion on limitations of two important processes of AODV protocol.

A. AODV protocol

On-demand approaches are source-initiated reactive mechanisms. When a node needs to communicate and no route toward the given destination is available in its routing table, a route request packet is issued and flooded in the network [6].

Once the first RREQ packet reaches the destination node or an intermediate node with a fresh route toward the destination is reached, a route reply (RREP) packet is sent back to the source node. The source node rebroadcasts the RREQ if it does not receive a RREP during a Route Reply Wait Time (RREP_WAIT_TIME). It tries discovery of path up to a given maximum number of attempts and aborts the session if it fails. As the RREP packet is routed back along the reverse path, the intermediate nodes along the path record a tuple for the destination in their routing tables, which point to the node from which, the RREP is received. This tuple indicates the active forward route.

AODV uses a timer-based technique to remove stale routes promptly. Each routing entry is associated with a route expiration timeout. This timer is refreshed whenever a route is used. Periodically, newly expired routes are invalidated.

Route maintenance is done using route error (RERR) packets. When a link breakage is detected, routes to destinations that become unreachable are invalidated. RERR propagation mechanism ensures that all sources using the failed link receive the RERR packet. RERR packet is also generated when a node is unable to forward a data packet for route unavailability.

Broadcasted route request and route error messages may be important if established routes are much bits error-prone. This can be demonstrated by simulation with the use of a realistic physical layer and a realistic wave propagation model.

B. Enhanced AODV

The AODV protocol has two major problems: a long end-to-end communication delay due to overtime induced by route discovery process and an important routing load and communication delay variation when the frequency of link failures is high. Since the publication of standardized version of AODV, many efforts have been made to improve it. The major challenge is to limit the frequency of route discovery process. Thus, several optimizations have been proposed in the literature. Among them, we note taking into account link quality in the route selection process and adapting timers to the network dynamics.

1) Tacking into account link quality: In a wireless network, several factors impact on the quality of links. Among others, we can cite the distance between nodes, obstacles in the propagation medium, interference in the environment of communicating neighbors. Highlighting the impact of barriers in the propagation medium is only possible with a realistic propagation model. Taking into account link quality in the establishment of communication paths is an important factor for efficient use of network capacity. Correct estimation of link quality and choice of effective metrics are major problematics for QoS routing protocols designers. To take into account link quality in the route selection process, several methods are proposed with different QoS metrics including bandwidth, delay, packet delivery ratio, Bit Error Rate (BER). Fei et al. [9] present the design and selection of appropriate routing metrics as the principal issue to guarantee efficient routing in self-organizing networks. They attempt to analyze, compare and summarize traffic-based routing metrics in the Expected Number of Transmissions (ETX) family.

Khaled et al. [10] propose a path robusteness-based quality of service routing for MANET. They proposed that before processing RREQ packet, an intermediate node must assure that its lifetime and the delay toward the neighbor from which, it receives the RREQ packet are above given delay-threshold and lifetime-threshold. At each hop, at least five checks are made and RREQ packet size increased with a node address. Destination node and source node must wait for copies (that have followed different paths) of RREQ and RREP packets until a timeout. The overhead (additionnal delay and routing load) and the complexity of this approach make problematic protocol effectiveness.

Some works, such as [11], use optimal link metric value in the path choice. Path selection choice based on optimal link metric value may not allow to get the best path. For example, for number of hops or retransmissions count-based metric, a path containing the link with the badest metric value m (compared to links of other feasible paths), is prefered to anyone, which links metrics values are upper than m, even if the other links quality of the first (path) are very good.

Some authors use additive and multiplicative metric to enhance AODV route discovery process. To find the optimal path in wireless mesh networks, Kim et al. [12] modify the standard AODV RREQ process. They propose that duplicate RREQs with better cumulative link metric value be forwarded, so that all the possible routes are considered. As link quality metric, they use an improved Expected Transmission Time (ETT) [13]. Their RREQ packet carries the cumulative link ETT value. They estimate the archievable throughput of their approach more than twice compared to standard AODV. We presume it is not necessary to re-broadcast duplicate RREQ packets. The intermediate node may note all possible reverse paths and retain as active reverse path to the source the better one according to the considered QoS metric. Their approach needs to be tested in MANET context with realistic simulation assumptions.

2) Taking into account network dynamics: Mobility of nodes is one of the essential issue of MANET. Taking into account the mobility of nodes is countered, first, by difficulties to adequately measure the mobility degree of a node. Many papers [14][15] propose to privilege nodes with low speed but network topology change is not local problem. A node may be fixed but if its neighborhood moves a lot, integrating this node into transmission path will not allow efficient communication.

Some authors propose to use link breakage prediction for packet loss avoidance. In fact, when intermediate node detects degradation of neighbor link quality on active route, it may anticipate route maintenance process. Then, source node is advertized to the probable path failure and anticipates route recovery process. This avoids transmission interruption. QoS metrics used in this method include received signal strength [16], packet delivery ratio of control packets [17]. Very often, the power of modeled signal depends only on the distance to the concerned neighbor node. It is known that obstacles in wave progation environment has an impact on signal strength [18][19]. Even if these metrics are accurately measured, the approach only anticipate the break of the link. The source must initiate a new route recovery process. The impact on delay improvement is not significant.

Amruta et al. [16] and Naif et al. [20] focused on accessibility prediction to restrict route discovery for future communications. Indeed, during the usual routing operations, a node can collect significant information enabling it to predict the accessibility and the relative mobility of the other nodes in the network. However, due to rapid change of network topology and since they are not actively maintained, these routes become obsolete. Macker et al. [21] study mobile routing path stability performance when constrained to use a distributed connected dominating set (CDS) control plane induced sub graph. They presente weighted, degree-based Essential CDS (ECDS) results alongside those obtained using a CDS temporal stabilization algorithm. Compare to full topology shortest path forwarding (SPF) their work provides significant improvement in lifetimes for the ECDS election stabilization mode but at the price of additional average routing stretch.

Kirthana Akunuri [22] proposes a novel on-demand routing protocol, Speed-Aware Routing Protocol (SARP) to mitigate the effects of high node mobility by reducing the frequency of route disconnections in a MANET. SARP identifies a highly mobile node which forms an unstable link by predicting the link expiration time (LET) for a transmitter and receiver pair. Their work decreases control traffic but deteriores other performance metrics like the throughput (i.e.,number of packets received).

C. AOMDV

In classical AODV, a route discovery process allows the source node (initiator of the route request) to obtain a single path for its data transmission. It must re-initiate the process when the used path is broken. Since each route discovery induces high routing load and latency, frequency of use of this process should be kept low so that the routing is effective. Multipath routing protocols have been proposed to meet this objective.

Ad hoc On-demand Multi-path Distance Vector (AOMDV) [23] is a well known multi-path routing protocol. The key concept of this protocol is the computation and recording of multiple paths (to a given destination) by route search. With these paths to a given destination, a node chooses a new route from backup routes when the active one (what was in use) is broken, thus avoiding having to re-initialize the route discovery process. A new route search process is only necessary when all the available routes fail. To form multiple paths, all duplicate RREQ packets received by a node are taken into account but not rebroadcast, as each RREQ defines an alternative route. Several studies have shown that the multipath approach improves AODV performance. However, in a context of very unstable network topology, AOMDV's performance are not stable.

Yufeng et al. [11] propose to improve the AOMDV protocol. They focus on the choice of path having a minimum number of retransmissions. However, a metric based on the number of retransmissions is not suitable in their context. Indeed, the route recovery process, the focal point for the effectiveness of reactive protocols, can not benefit from this improvement because the RREQ packet is not forwarded. Authors in [24] highlight a major drawback due to the fact that the relief routes are not maintained. Source node does not know if a given relief route is still valid when it is needed. The use of a obsolete path lead to increased average delay and jitter. They present two main contributions to improve the robustness of standard AOMDV protocol:

- the decentralized multi-path. The basic idea is to allow intermediate nodes to have multiple paths and locally repair broken routes,
- by a cross-layer approach, they take into account links reliability in the route choice process.

D. Analysis

In this sub-section, we present limits of the first received RREQ packet based route choice and issue of route maintenance especially in the case of multi-path routing. The *first RREQ* consideration approach means the selected path is the one with the better Round Trip Time (RTT). This path is the sorthest one in term of hops count if all links are considered as similar. This path is the best path for control packets but not obviously the best for the data packets. Indeed, the RREQ packets, like for most of routing control packets, are small size packets. They are less vulnerable to interference. We study the impact of the packet size on the number of transmissions required to successfully communicate on a link and on bit error rate (BER). Simulation conditions are simular with those presented in presented in Section IV. These results show that the number of retransmissions required to successfully transmit on a link increases with the packet size (see Figure 1). Thus, a link that is very reliable for control packet transmission may require several retransmissions for successful data packet. It is not conceivable to use reasonably sized packet for route discovery (close to that of data packet) as this will cause constantly high routing load and much of the bandwidth is consumed by routing overhead.

Another questionable process of on-demand routing protocols is their route maintenance process. Contrary to proactive routing approaches, in on-demand routing methods, nodes maintain information only for active routes. In [24], it is shown that in mobility situation, AOMDV does not reach the expected performance because the backup routes are obsolete when the active route is broken.

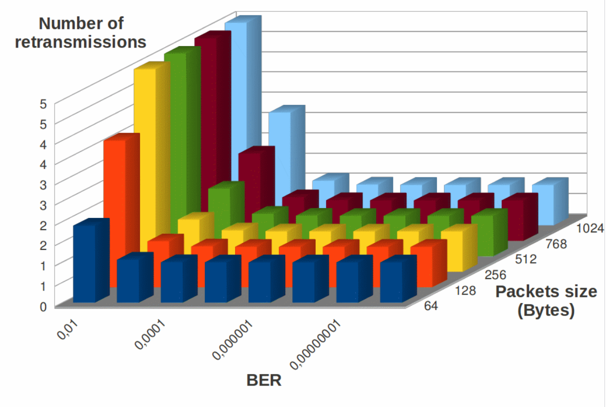

Figure 1. Number of expected retransmission according to packet size and BER link

III. QoS-BASED ON-DEMAND ROUTING PROTOCOLS

In this section, we present the PR-metric and three variants of AODV based on this metric. However, comprehensive presentation of this metric is beyond the scope of this paper.

A. *QoS metric*

The most commonly metrics used in QoS routing are bandwidth, delay, packet delivery ratio and bit error rate. Authors in [25][26][27][28][29] highlighted the problematic of link quality estimation and metrics design. An inaccurate design of link metric causes non-optimal route construction and thereby leads to end-to-end performance degradation. To partly solve this issue, retransmissions should be avoided whenever possible. BER is highly related to retransmissions. BER has a direct impact on Packet Delivery Ratio (PDR) and end-to-end delay, however, this metric has many drawbacks. Indeed, BER criteria is quite hard to measure in practice. A first method consists in injecting probe packets in the network. This method generates an additional load for the network [30]. Another approach consists in sending impulses and measuring the impulse response associated with a transmission. The main drawback is that this method requires an adapted physical layer. An estimation of all these disadvantages is presented in [25]. Moreover, using BER as an additive metric induces long end-to-end transmission path [31]. These long paths with an overall good BER value would potentially permit a better packet delivery ratio, but they generate long delay and induce poor throughput. Indeed, first, long paths increase intra-communication interfer-ence. Second, in mobility context, long path is very vulnerable.

For this study, we use a new metric based on the expected number of retransmissions required to communicate successful data packet on this link. Let us call it PR-metric. With PR-metric, distance between a node and its neighbor will not be 1 but $1 + a * (n - 1)$, where n represents the average number of transmissions required to make a data transmission successful and a is a parameter to weigh retransmission cost. For retransmission, we want to design a transmission made after the first issue (after the first transmission attempt). The coefficient a is the ratio between the average time required for a retransmission over the time necessary for an initial successful transmission. Statistical analysis and results permit us to estimate a to 0.65 with 0.03 as standard deviation. Note that a is a mean value that represents retransmission cost. The experimental setup for this evaluation is similar to that is presented in Section IV. We investicated the simulated communications delays. Comparisons of delay where communication required a single transmission (one attempt) to those who need several retransmissions allowed us to obtain this value of a.

To evaluate this metric, we only have to get the number of packet transmissions. This information is available at the MAC level (it is a part of the communication statistics at the MAC layer) and, by a cross layer approach, is operated at routing level. We remind that there is no need to use special probes as in the estimation of most metrics. When the used packet size is small (like hello packet), the number of transmissions is almost always 1 (no retransmission). The large packages allow to better estimate the quality of a link with this metric. In our protocols all packets are taken into account. This metric has a direct impact on delay and throughput. Contrary to the well-known metrics like BER or ETX [32], it takes into account real time network load. Its estimation is local. It does not induce a significant routing load or a large computation time. It is a good compromise between the number of hops criterion and the BER or ETX criterion, which induces selection of long route [31].

B. *QoS routing approach*

QoS routing approach In a cross-layer approach, we use this criterion at the network layer. The objective is to avoid data transmission on bad paths in terms of BER. The following sub-sections present how we enhance routing protocols with BER information.

C. *AODV-BL-PR*

The basic idea of AODV-BL-PR is to remove from route establishment process poor quality links. Thus, the route search process will use a sub network with good quality links. AODV-BL-PR picks out AODV where we apply blacklisting approach to route recovery process. With AODV-BL-PR, when an intermediate node receives a RREQ packet, it compares the PR-metric value of link on which, this packet is received to a predetermined threshold. If this PR-metric value is higher than this treshold, the packet is discarded, otherwise it is managed as in standard AODV. Indeed, if this node forwards this request, it contributes to establish a bad path, which may cause high packet loss and high delay due to possible several retransmission attempts. Better paths may be found. We set this threshold to 2. We estimate that, in mobility context, after 2 attempts to transmit data, the path used is no longer valid. Note that maximum number of retransmissions at MAC layer is 4 for our test. We note that a control message (usually lighter) can be successfully transmitted on a poor quality link when a normal payload message can not be transmitted. With this route selection approach, paths containing bad links are disregarded.

This will also limit the dissemination of RREQ messages and then reduces routing overhead.

D. AODV-sum-PR

The basic principle of AODV-sum-PR during the route search process, is the choice of better route among the different possible routes between the source and the destination. To design this protocole, two main modifications are made to standard AODV, namely QoS-information dissemination and duplicate RREQ packets process by intermediate node.

- QoS-information dissemination: for AODV-sum-PR, RREQ and RREP packets are extended with the cumulative PR-metric (C-PR-metric) field. Source node initializes this metric to 0.0. An intermediate node increases the value of C-PR-metric by the PR-metric of the link on which, it received the packet. The intermediate node also integrates reverse path into its routing tables. Each entry is improved with the C-PR-metric as QoS-metric. The RREP packet also carries the C-PR-metric. The field is, this time, initialized to 0.0 by the destination node or to the current value of entry related to this destination by intermediate node, which initiates the RREP packet.
- Duplicate RREQ packet process: contrary to standard AODV, an intermediate node manages duplicate RREQ packet. Indeed, if the C-PR-metric of a duplicated RREQ packet is lower than the recorded one, the entry for source node (reverse path) is updated: the previous hop to the source node will be the new transmitter. Finally, the source node obtains a path to the destination with the lowest C-PR-metric value.

Note that intermediate node does not need to re-broadcast the duplicate RREQ packet and does not need to integrate the PR-metric value of all its neighbors as control packets header information, as widely done.

In Table I, we summarized the duplicate packet processing.

TABLE I. SAMPLE OF DUPLICATED PACKET PROCESSING ALGORITHM

```
for the concerned reverse path
if new C–PR–metric < current C–PR–metric
            update next–hop
            update C–PR–metric
else
            drop the packet
```

E. AODV-new-timer

AODV protocol has several timers to manage the status of known routes and links with the neighborhood. These timers are updated through the various received packet management processes. The values of these timers are crucial for the protocol effectiveness, specially in the route announces by intermediate nodes. Indeed, an intermediate node, which knows a route to a desired destination, responds by RREP packet to the RREQ request. The announcement of an obsolete route leads, from the first attempt at data transmission, to the use of route repair process by a RERROR packet diffusion. In most different experiments, these parameters have the same values in a static context and a dynamic context. However, in a context of mobility nodes, the neighborhood of a node changes quickly.

The basic idea of AODV-new-timer is to allow nodes to detect, as soon as, possible broken links or new links established. Then, in this enhanced protocol, we reduce the timers associated to the various recorded routes, established links with neighbors and waiting for a response (hello timer, route validity timer, waiting RREP packet timer, etc.). These timers are used to manage routes and links validation or recovery processes. To highlight the impact of these parameters and make a judicious choice of values, we have performed simulations and conduct a statistical study of the results of message exchanges. The simulation conditions are presented in Sub-section IV-B. The average speed of the 60 nodes used is 12m / s. 10 simultaneous end-to-end transmissions are initiated during 165s. We focused on the number of RERROR packets issued in the network. This performance parameter is used to highlight the level of network stability. The four sets of timers are presented in Table II. The obtained results are shown in Figure 2.

TABLE II. DIFFERENT SETS OF AODV TIMERS VALUES

Timer Parameter	Set1	Set2	Set3	Set4
MY_ROUTE_TIMEOUT	15s	10s	5s	2.5s
ACTIVE_ROUTE_TIMEOUT	15s	10s	5s	2.5s
REV_ROUTE_LIFE	10s	6s	3s	1.5s
BCAST_ID_SAVE	10s	6s	3s	1.5s
MAX_RREQ_TIMEOUT	15s	10s	5s	2.5s
RREP_WAIT_TIME	2s	1.0s	0.7s	0.4s
HELLO_INTERVAL	2s	1s	0.5s	0.3s
BAD_LINK_LIFETIME	6s	3s	1.5s	0.8s

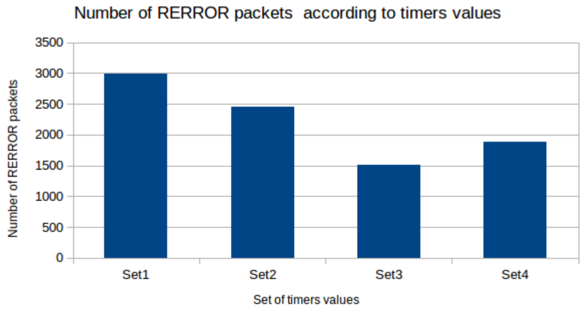

Figure 2. Number of RERROR packets according to the set of timers values.

These results have allowed us the choice of set 3 values (see Table II). It is these values that are used in the rest of the document for AODV-new-timer.

The new parameters are exhaustively presented in Table III. AODV-st means usual AODV. This coordinated reduction globally means that a node more frequently inventories its links and routes.

With this approach, we want to know the determining factor between taking into account link quality or a convenient control of neighborhood information for better performance in mobility context.

In summary, the reduction of route timeout value to 5s means that a path that is not used 5s ago is considered obsolete. The default value in standard AODV is 10s. The source waits

TABLE III. DEFAULT (AT LEFT) AND MODIFIED (AT RIGHT) AODV PARAMETERS FOR OUR TESTS

Timer Parameter	AODV-st	AODV-new-timer
MY_ROUTE_TIMEOUT	10s	5s
ACTIVE_ROUTE_TIMEOUT	10s	5s
REV_ROUTE_LIFE	6s	3s
BCAST_ID_SAVE	6s	3s
MAX_RREQ_TIMEOUT	10s	5s
NETWORK_DIAMETER	30 hops	10hops
RREP_WAIT_TIME	1.0s	0.7s
HELLO_INTERVAL	1s	0.5s
BAD_LINK_LIFETIME	3s	1.5s

less time (0.7 instead of 1.0) to restart a new request if it receives no response to a previous query. The network diameter is reduced to 10 instead of 30. We estimate that over 10 hops it is impossible to communicate in node mobility context. A HELLO_INTERVAL timer set to 0.5s instead of 1.0s, means that nodes should test their neighborhood more frequently.

IV. PERFORMANCE EVALUATION

In this section, we first present our simulation environment, we then present the results of simulation tests and analyze the performance of different protocols.

A. Simulation conditions

Simulation hypotheses have a major impact on the analysis of protocols' effectiveness. In wireless networks, the main factors that impact the probability of successful packet reception are the radio propagation environment, interference from other transmissions and link breakages due to dynamic topology of ad hoc network. On-demand and link states routing protocols suffer differently from these factors. To compare the efficiency of protocols, the effets of these factors must be taken into account. In this sub-section we want to highligth the impact of these simulation conditions.

Most research studies rely on simulation to show the effectiveness of their proposal. However, they do not take into account any environment when modeling propagation channel. They suppose that two nodes can communicate based on various empirical formulas. Often, the free-space model is used, only the direct ray between transmitter and receiver is considered and no obstacle disturbs transmissions. The two-ray-ground approach is also quite simplistic to compute such interferences. A realistic propagation model should consider path loss, fading and shadowing effects. If the environment is not considered, the obtained results can be biased and rather optimistic, since the influence of bad links is underestimated. In [18][19], authors show that interactions with wave propagation environment affect significantly link quality.

To better estimate the quality of links and to take into account the impact of propagation medium on the quality of communications, we use a realistic propagation simulator developed by XLIM-SIC laboratory [33] called Communication Ray Tracer (CRT). This software allows the modeling of the electromagnetic wave propagation in 3D environment. The paths between two points (transmitter and receiver) uses a 3D ray tracing technique. Thus, for a selected link, it determines the existing paths and their own characteristics like delay, attenuation, phase and polarization. These parameters depend on the environment. It allows to fully characterize narrow and broad band channels and thus provides a realistic approach to multipath. With CRT, we conduct a semi-deterministic simulation of the entire chain of transmission (encoding, modulation, sound effects, demodulation and decoding). The impulse responses (IR) from the simulation are precisely computed and can thus be used, processed or analyzed easily afterward. From these impulse responses, they calculate the BER of the radio links by counting errors to the message originally sent.

Hamidouche et al. [18] highlight the overly optimistic results, when using free-space model propagation, compared to the ones provided by CRT. In these results, while the Free-space model provides a 100% as packet delivery rate, the CRT model offers about 60%. When the average number of hops is 1.2 in free-space, the CRT model offers a minimum of 2.5. To experiment quality of service, simulation should compute correct attenuation and error rate by taking into account not only shadowing and fading but also obstacles and multipaths effects.

Multi-communication effects must also be considered in a suitable way. Interference is an inherent property of wireless networks, which affects network efficiency as well as routing protocol performance [34]. As pointed out by Gupta and Kumar [35], the degradation of performance is observed when the number of nodes increases because each node has to share its radio channel with its neighborhood. Thus, in order to route data packets over non congested links and maximize overall network throughput, a protocol should focus on using available capacity of suitable links. On this subject, Jain et al. [36] advocate that routing or transport protocols in ad hoc networks should provide appropriate mechanisms to push the traffic further from the center of the network to less congested links. Some researchers emit important assertions about the correlation between number of nodes and source-destination throughput. Gupta and Kumar [35] prove that when the number of nodes n increases, the throughput per source-destination pair decreases approximately as $\mathcal{O}(1/n)$. Hekmat and Van Mieghem [37] reveal the existence of a network saturation point, after which, the network throughput no longer increases with respect to the number of nodes. Nevertheless, these assertions should be verified in realistic communication conditions.

In mobility situations, unrealistic mobility models (use of constant speed, pause time method, etc.) are very often used and interactions between mobile entities are not taken into account. It is shown in [38] that mobility model may drastically affect protocol performance.

B. Experimental setup

To compute more real simulations, we use a realistic wave propagation model taking into account environment characteristics. Therefore, we enhanced NS2 [39] with a ray-tracer simulator, Communication Ray Tracer (CRT) [33], that has been developed at the XLIM-SIC laboratory. CRT simulator provides a 3D ray-tracer wave propagation model. It takes into account the geographical data, electrical properties of materials, the polarization of the antennas, the position of the transmitters and receivers, the carrier frequency and the maximum number of interactions with the surrounding obstacles.

To realistically model node movement, we use the VANET-Mobisim [40] software. Node speed is computed by this software. The mobility model implemented is more realistic than widely used ones [41][42][38]. Paths are defined in correlation and consistency with our environment model. VANET-Mobisim is also easily interfaced with NS2. Specifically, VANET-Mobisim uses a mobility file in XML format, which contains all the detailed informations of the microscopic and macroscopic models that govern mobility of nodes. The mobility model used in this software takes into account the environmental parameters of the mobile nodes (traffic lights, speed limits, etc.) and possible interactions between mobile nodes. A node may thereby accelerate, decelerate according to environment constraints.

The global parameters for the simulations are given in Table IV.

TABLE IV. SIMULATION PARAMETERS.

Parameters	Values
Network simulator	ns-2
Simulation time	180s
Simulation area	1000m*1000m
Maximum number of transmissions	4
Transmission power	0.1w
Data types	CBR
Data packet size	512 bytes
MAC layer	IEEE 802.11a

We also use a realistic model of the Munich town (urban outdoor environment, see Figure 3), obstacles (building, etc.) are printed red. Dots represent nodes. Other real environments could be used in a more comprehensive study.

As routing protocols, we compare AODV-st, the standard AODV protocol [6], to the three enhanced ones presented in Section III.

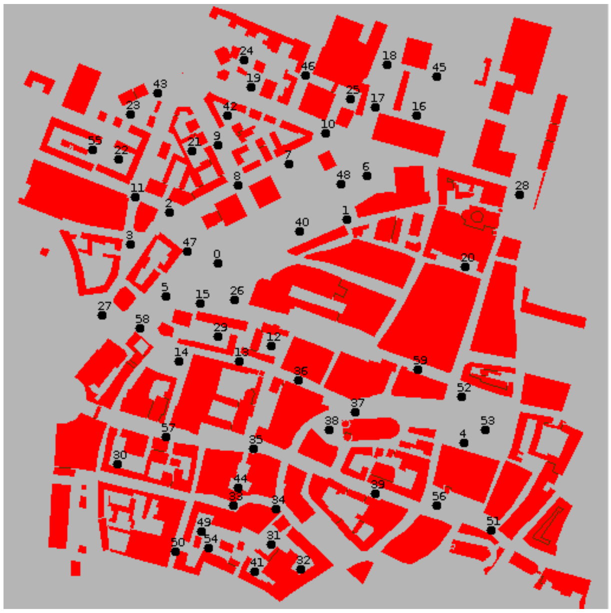

Figure 3. Simulation environment when number of nodes=60. Obstacles are printed red.

C. Simulation results

In this section, we study the impact of mobility on performance of the four protocols. 60 mobile nodes move in the Munich town environment (Figure 3). Their average speeds range from 4m/s to 20m/s. 10 simultaneous end-to-end transmissions are initiated during 165s. As performance parameters we rely primarily on average end-to-end delay of data packets, PDR and Routing Overhead (RO). End-to-End Delay concerns only successfully delivered packets. PDR is the ratio of the number of successfully delivered data packets over the number of sent data packets. Routing overhead is the number of routing protocol control packets. It permits to evaluate the effective use of the wireless medium by data traffic.

In Figure 4, we present data transmission delay evolution according to the average node speed. These results show that AODV-new-timer outperforms the standard AODV and the two PR-metric based ones (AODV-BL-PR and AODV-sum-PR). The good performance of AODV-new-timer is explained by the fact differend waiting times are reduced and the near real time knowledge of neighborhood avoids node to process obsolete paths. Node implementing AODV-new-timer detects links breakage quickly. For QoS-based AODV (AODV-BL-PR and AODV-sum-PR), determining QoS routes requires substantial time and with node mobility, established routes become obsolete quickly. Thus, they are less efficient in delay parameter than AODV-st.

PDR evolution according to node speed is presented in Figure 5. Here again we see the same trends. The AODV-new-timer is better than the three other protocols. PDR values are higher than 58%. The paths established by the QoS protocols are longer than those established by the standard protocol. Their average path length is 3.4 against 2.6 for the standard protocol. In situations of mobility, long paths are more vulnerable. Also, over long paths, intra-interferences are more important as intermediate node may not receive a packet and retransmit another at the same time. These contribute to the poor performance in PDR and delay for these QoS protocols compared to the standard one. We also note that the number of packet loss on the first attempt of data transmission is 20% of total packet loss for AODV-st and PR-based ones against 13% for AODV-new-timer. This is explained by the use of obsolete path attempt by AODV-st and PR-metric based AODV.

Others criticism of blacklisting approach applied to AODV (AODV-BL-PR) may be made. An analysis of trace files shows that the percentage of transmission failures due to lack of route is high (10%) with AODV-BL-PR. This is explained by the fact the use of a threshold on the PR-metric to decide whether forward a Route Request packet may lead to ignore several alternative paths, thus reducing the reliability of the entire network. We remind that with this protocol, the links with PR-metric higher than 2 (equivalent to 3 transmission attempts) are excluded from the route search process. Finally, note that ignoring some bad links may induce a loss of network connectivity. In [43], it is emphasized that blacklisting policy could filter routing options severely, limiting the efficiency of the routing algorithm if an improper threshold is chosen.

A thorough analysis of the simulation shows that the majority of communications where source and destination are far apart from each other have failed. Established routes become obsolete even before the first data packets arrive at the destination.

These show that better neighborhood information control is more important than taking into account link quality for AODV efficiency.

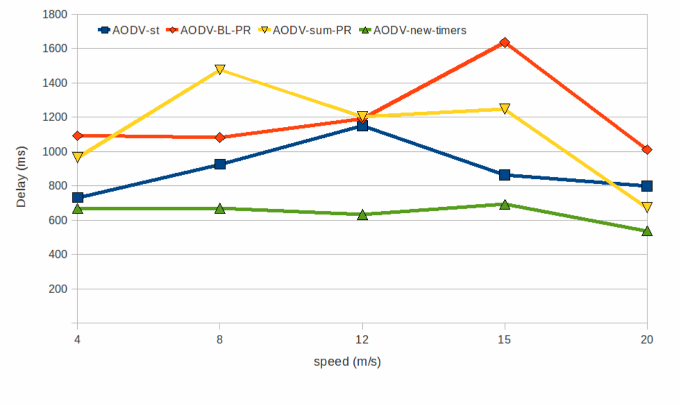

Figure 4. Delay evolution when speed increases.

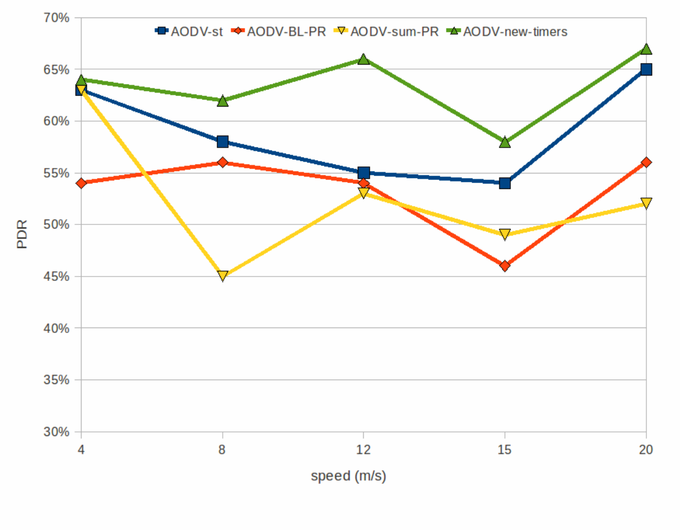

Figure 5. PDR evolution when speed increases.

Protocol's performance in RO parameter is presented in Figure 6. The high cost of AODV-new-timer is expected since Hello and RREQ messages emiting frequency increased. Its RO is, as expected, double that of AODV-st in a context of low mobility (¡= 8m / s). This difference diminishes when the average node speed increases. This is explained by the fact that with AODV-new-timer, the recourse to route recovery process and therefore the dissemination of REROR packets is less. The better performance of QoS-based AODV compared to standard one can be explained by better paths selection. In addition, blacklisting approach of AODV-BL-PR limits the dissemination of RREQ messages. For AODV-new-timer, the RO may be very high in a dense network and thus may impede the good performance of this protocol. A choice of timer values, depending on the volatility of links, could help ensure better compromise.

Figure 6. RO evolution when speed increases.

We also note that the curves performance are not monotonic. This denotes the complexity of the mastery of the network topology in mobility context. The jitter is high and raises problems for use of these networks in multimedia communications, especially voice communications.

V. CONCLUSION AND FUTURE WORK

The performance of AODV Protocol held in the efficiency of route discovery process. In an unstable links context, routing load and jitter may be significant. The main improvements are to limit the dissemination of route request messages and reduction of the frequency of route recovery process solicitations. However, in a context of mobility, link quality estimation procedures and better paths choose mechanisms must be efficient in terms of bandwidth and time consumption.

In our study, we tested the effectiveness of different QoS-based methods under realistic wave propagation model and realistic mobility model. For QoS metric, we use number of retransmissions count-based metric. Although we used a simple and effective method for link quality estimation, the results show that taking into account the quality of links is not effective for the MANET performances improvement. The additional complexity, induced by QoS management, increases delay and precipitated the obsolescence of the links.

To achieve better performance in high speed MANET context, the real challenge is the effective control of node neighborhood and accurate established routes lifetime and waiting RREP packet timeout value.

A more comprehensive study of the problematic of on-demand routing protocol performance could concern other real environments (than Munich town one) and a refinement of the penalty coefficient due to retransmissions.

A solution where the inventory frequency of the neighborhood depends on the network dynamics might improve the performance of on-demand routing approach in mobility contexts.

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