# Routing Protocol with Link Quality based for Ad Hoc Networks in an Urban environment

**Abstract.** A mobile ad hoc network (MANET) is a set of mobile nodes that create a dynamic topology by cooperating to manage communications. It is characterized by the absence of a central administration, wireless links, sensitivity, mobility, and limited energy. Routing in such a network is a major challenge due to these constraints. Furthermore, there is another important factor that may affect the efficiency of routing: the environment. In reality, an urban environment includes restrictions affecting mobility and signal quality, rather than many other signals and magnetic effects that affect the wireless transmission. In order to design a reliable routing protocol and resolve this problem, we proposed a multipath routing protocol, LQCA-ue (Routing protocol with Link Quality based for MANETs in Urban environment). We include a fitness function to select the optimal path based on the link quality and stability constraints. The performance of our proposal is compared with AOMDV and evaluated in four different mobility models, realistic and random. The evaluation of our protocols showed interesting results in terms of PDR, which increased by 11%, and overhead, reduced by up to 50% compared to AOMDV.

**Keywords:** Mobile ad hoc networks, multipath routing protocol, stability, signal quality, Urban environment.

## 1 Introduction

In the last decades, wireless networks have been rapidly evolving due to the flexibility of their interface, allowing users to move while staying connected easily, regardless of the device used. The communication between terminal equipment can be direct (peer-to-peer) or via base stations (such as GSM). This technology offers multiple benefits to humanity, including reducing network time, requiring less hardware, and the mobility of nodes. Ad Hoc networks are a particular type of wireless network.

A MANET (Mobile Ad hoc Network) is a set of mobile nodes equipped with a battery and a wireless interface used to establish communication between nodes, forming a dynamic topology that changes periodically due to the mobility of nodes and the limited transmission range. There is no need to use any communication equipment in MANET, as each node acts as a node and a router simultaneously. [1]

MANETs use a multi-hop strategy to ensure communication between nodes. However, the characteristics of mobile ad hoc networks and their nodes, rather than the nature of radio transmission (which may be affected by environmental factors), make the communication between nodes a major task. Routing is the process of discovering one or more paths between the source node and the destination node to enable the transfer of data packets in a multi-hop network, because the source node may have to transmit them through intermediate nodes to reach the destination node. [2]

The routing protocol in MANET can be classified into three categories: proactive, reactive, and hybrid. In a proactive protocol, routing tables have routes in advance. It identifies the network topology by maintaining a global view of all nodes at every point, which is ensured using periodic exchanges of control packets (that contain information about nodes that are the first and the second hops away). The nodes calculate paths after each update to guarantee a fresh path to the destination node. We have OLSR (Optimized Link State Routing Protocol) [3] as an example. Contrary to the proactive protocol, the reactive protocol discovers paths on demand using a request-response mechanism. When a node needs a route, it launches a discovery process by flooding a route request packet (RREQ) in the whole network to reach the destination and create a path between the source and the destination node to establish communication. If a link break occurs, the maintenance process is invoked; as an example of reactive protocol, we may mention AODV (Ad hoc On-demand Distance Vector) [4] and DSR (Dynamic Source Routing) [5]. The last type is hybrid, which combines the two approaches to leverage the advantages of both. Hybrid protocols organize the network into two zones. They apply proactive routing in the first zone (local) to discover the neighborhood (a predefined number of hops) and reactive routing outside it (such as ZRP protocol: Zone Routing Protocol) [6]. Reactive protocol may suffer due to the diffusion process, which is repeated each time a path is broken. This may degrade the network performance and delay the data transmission. To address this issue, a multipath approach has emerged to find multiple paths through the same discovery process. Indeed, if an active path breaks, instead of starting a new path discovery, an alternative path is chosen to resume the transmission immediately. [2] [1]

Hence, the traditional approach of routing in mobile ad hoc networks is to adopt a single active path between the source node and destination node, and to use one constraint, such as hop count, to evaluate the found paths. This choice is not always the optimal one, as the hop count ignores other important factors that considerably impact the network and the reliability of data transmission, leading to consuming more energy, generating huge control packets, and reducing the lifetime of nodes. [7]

The main characteristics of the environment that should be taken into consideration to select the optimal path for the purpose of improvements at the protocol level are energy, stability, throughput, quality of service, etc. Protocols must be optimized to conserve node resources (energy, bandwidth, memory, and computing power) as the nodes have generally limited energy and modest hardware capacities. Furthermore, there is another important factor that affects the reliability of the protocol: the environment. The urban environment is subject to many challenges due to its complex characteristics (restricted mobility behavior, presence of obstacles, interference, and noise, etc.), which affect the signal quality. Most of the current studies don't address this issue and don't evaluate their approach in such a realistic environment. [8]

One of the fundamental challenges of MANETs is the design of efficient routing protocols that take into consideration the characteristics of MANET in order to determine an optimal path based on multiple constraints and enhance the network performance. Additionally, it should be adapted to an urban environment.

According to some studies [9] [10], the authors show that the mobility model has an impact on the performance of a routing protocol. Consequently, it's important to evaluate the proposed approach under different mobility models, especially a realistic mobility model [9]. It is important to simulate the protocol and evaluate its performance under a variety of scenarios. It's a crucial phase to show the efficiency of the routing protocol. The simulation uses a mobility model that describes the behavior of node movement, their locations, speeds, restricted mobility, etc. In the literature [2], there are two main categories of mobility models: Random, such as Random Waypoint (RWP), and Geographical models, such as the Manhattan mobility model.

Mobile routing in urban areas is an important research topic. Contrary to most of the existing works that use the RWP model as a mobility model (non-realistic), we focus on the problems of improving mobile ad hoc routing in urban areas. In this paper, we present a novel stable multipath routing protocol for MANET in urban environments, called LQCA-ue (Routing protocol with Link Quality based for MANETs in Urban environment). LQCA-ue uses a method based on cross-layer topology to ensure link quality and better stability of the paths from a source node to a destination node. We combined stability and quality function to select an optimal path that provides higher reliability. Our protocol is evaluated in four different mobility models, one of which reflects an urban environment.

The following highlights this study's contributions:

1. Develops a reactive process for discovering multiple link-disjoint paths between a source node and a destination node based on:

- The link quality function considers the SNR (Signal Noise Ratio) to detect the signal degradation and ensure the reliability
- The link stability function chooses the most stable path based on mobility behavior to reduce link failure caused by mobility and minimize packet loss.

2. Proposes a new multi-objective function for the selection of the best paths based on two constraints:
3. Evaluates our solution using four mobility models: RWP and RW (Random Walk), Manhattan, and the Obstacle mobility model.

The paper is organized as follows. Section 2 presents a review of related works in the literature. In Section 3, we describe the proposed routing protocol LQCA-ue. Section 4 presents the performance evaluation and results discussion. Finally, Section 5 concludes this paper.

## 2 Related Works

In this section, we will present some existing work that addresses the problem of routing protocol in mobile ad hoc networks in order to ensure communications between different nodes and improve several performance metrics such as packet delivery ratio (PDR), end-to-end delay, energy, and overhead. Therefore, the researcher tries to choose one or multiple constraints that have a considerable impact on these metrics.

Since the majority of mobile nodes run on limited battery capacity, energy conservation is a crucial consideration when creating routing protocols for ad hoc networks.

The authors [7] proposed the LTAOMDV (Life Time AOMDV) routing protocol based on energy constraint, taking into account the energy remaining of nodes in the selection path process. They collect the remaining residual energy of nodes for each discovered path and classify paths into three classes using two predefined thresholds α and β: low (low energy level), medium, and high. The objective of this solution is to extend the lifetime of the network by avoiding paths having a low energy level, which may increase the number of nodes that die. However, this is not always a good decision because we may have a critical node (low energy level) in a high path class. Furthermore, this solution ignores other important constraints like stability and quality.

EE-OLSR [11] (Energy Efficient OLSR) has been proposed by integrating the energy constraint into the OLSR. It evaluates a node using both the remaining energy and the lifetime of a node to select MPRs to increase the network lifetime and reduce MPR recalculation. Each node declares a corresponding heuristic value called "Willingness" classified into three classes (low, medium, high). This value is used to select nodes that will become MPRs. EE-OLSR proposes another mechanism that can be used in the OLSR protocol to reduce the use of sleep mode to conserve more energy. This mechanism allows the wireless interface of neighboring nodes to be reached during the exchange of unicast messages. However, this solution may improve the network performance as not only does the energy cause link failure, but also mobility and signal quality. A routing protocol has been proposed [12] and [13] to extend network lifetime by minimizing link breaks caused by a dead node. All of these works solve the energy conservation problem; However, they use techniques based on the remaining energy only. A node with the lowest energy level does not mean it will go off first, as there is another factor, which is the energy consumption rate, where a node with a higher energy level may die faster because it is under high load.

The MDA-AODV (Mobility and Direction Aware AODV) [14] protocol is an extension of AODV that takes into account the mobility constraint. It assumes that all nodes are equipped with GPS to determine the coordinates of each node. An adaptation is made to the Hello message of AODV by adding two fields representing the node's current position and speed. The protocol uses this information from two successive Hello messages to determine a node's flag by comparing their values. The flag takes three values: 0 if the distance is fixed, 1 if the distance increases, or -1 if the distance decreases. Each node records the speed and the flag in the routing table. During the discovery process, if a node's speed exceeds a specific threshold, it will ignore the RREQ message. If the RREQ message reaches the destination node or an intermediate node that has a valid path to the destination node, the speed of the node transmitting the request must be lower than the average speed of all neighbors of that node. In this case, an RREP will be sent to the source node; otherwise, the RREQ message will be ignored. MDA-AODV builds a stable path based on mobility parameters, reducing path failure and increasing path lifetime. However, it requires GPS for all nodes, which has certain limitations; moreover, it consumes more energy.

Furthermore, a combination of link stability and energy constraints is the subject of several works. The authors [15] proposed a new multipath energy-efficient routing protocol using a Fitness Function (FF-AOMDV) based on the standard AOMDV protocol with the integration of three constraints: energy and mobility, and hop count.

The proposed protocol selects the path having a high energy level and the minimum distance from the source to the destination, which reduces the energy consumption and end-to-end delay. However, the high-energy-level path may be composed of an energy-exhausted node, which leads to quick node failure. Also, the link quality constraint is not taken in this approach, which means that it may choose a noisy path that has a high loss rate. ESMRua multipath routing protocol [16] is proposed based on two constraints: energy and stability. It suggests a fitness function to evaluate paths and select the optimal path. The energy function takes into consideration both the energy consumption rate (formally, the drain rate) and the remaining energy. The stability function is measured by the coefficient of variation of all distances observed (distribution). This protocol is evaluated in a realistic mobility model: the Manhattan Model. The performance result shows that this combination improves network performance and reduces energy consumption. Nevertheless, they ignore the quality that may considerably affect the performance of the proposed protocol.

In this discussion of different existing constraints in MANET, we should mention the signal quality. The signal quality is a unique metric compared to energy and stability as it reflects the received signal, which is affected by some environmental factors that affect to packet delivery rate, such as interference, fading, noise, etc. [2]. In the literature, LQE (Link Quality Estimator) metrics are classified into two main categories: physical-based and software-based. Physical-based metrics are derived directly from the physical layer. We have [17]:

- RSSI (Received Signal Strength Indicator): It defines the signal strength of the received packet (in dBm)
- SNR (Signal Noise Ratio): Defines the difference between signal strength and noise. SNR can be estimated from the RSSI value during packet transmission, and the noise is measured when the channel is clear (absence of transmission).
- LQI (Link Quality Indicator): provides information on signal quality. This metric is proposed in the IEEE 802.15 standard, but no definitive formulation of its measurement range or calculation is given (manufacturer-specific metric).

Furthermore, we have a second class: software-based; metrics are obtained from the higher layers using packet transmission [17]:

- PRR-based: The PRR (Packet Reception Ratio) metric, same as the PDR (Packet Delivery Rate), is the ratio of successfully received packets to the number of packets sent over a window w (receiver-side estimator).
- RNP-based: The RNP (Required Number of Packet Retransmissions) metric counts the average number of packet transmissions/retransmissions required before successful reception (sender-side estimator). It typically uses passive monitoring by periodically broadcasting control packets for a short duration.
- Score-based: Score-based metrics provide a score or label that assesses the quality of the link and defines it within a certain range. Typically, a score-based metric allows combining multiple metrics to improve the accuracy of the estimator.

ESRP [18] (energy and signal strength-based routing protocol) uses an energy and signal strength-based, reliable route fuzzy-based scheme to estimate the signal strength and bandwidth. It controlled the congestion in the network by balancing the load and reducing energy consumption. This approach has optimized network consumption, reduced packet latency. However, the protocol isn't evaluated in a realistic mobility model. A study [19] proves that the PRR metric cannot differentiate between stable and unstable links (a link is unstable if a minor change in the environment degrades the delivery rate), and where a sudden degradation occurs, leading to poor estimation that affects network performance. To overcome this drawback, an improvement to PRR was introduced in Window Mean with EWMA (WMEWMA) [20], which is a simple quality estimator based on the receiver-side PRR metric. It relies on the concept of passive monitoring to avoid overhead. WMEWMA applies an EWMA (Exponentially Weighted Moving Average) filter to estimate link quality based on the current recorded PRR and the previous (historical) PRR to filter out its transient fluctuations. Looking at the results, the new metric provides a more stable estimate that has some resilience to PRR fluctuations. F-LQE (Fuzzy Link Quality Estimator) [21] is a score-based receiver-side quality estimator that estimates link quality based on four link quality properties: PDR (packet delivery), skew (the absolute difference in PRR within the forward and reverse links between two nodes), stability (the coefficient of variation of the PRR over the last 30 packets), and channel quality (as a function of the SNR). These properties are defined in terms of natural range (high or low) and combined using fuzzy logic to express link quality. F-LQE applies the EWMA filter to provide stable link quality estimates. The F-LQE score ranges from 0 to 100, with 100 representing the best link quality and 0 the worst. Experimental results show that F-LQE achieves good reliability and stability performance compared to several quality metrics such as PRR, WMEWMA, ETX, and RNP. However, the quality metrics used in the comparison are single metrics that cannot evaluate a single link property. Furthermore, F-LQE has a higher computational complexity.

Authors [22] have proposed a new routing protocol called RMQS-ua (Reliable Multipath Routing Protocol based on Link Quality and Stability in Urban Areas) designed for the urban environment. They used a combination of stability and link quality constraints to select the path that has better link quality and more stable links to guarantee reliable data transmission. A combination of signal-to-noise ratio SNR and an enhanced packet reception ratio PRR to evaluate link quality, and the exponential moving average (EMA) for distance to estimate the link stability. The protocol was simulated in the Manhattan model. The results show that RMQS-ua enhances the network performance and conserves more energy. However, this protocol ignores the energy constraint, which may increase dead nodes and affect the network lifetime.

In recent years, researchers have moved toward applied genetic algorithms and machine learning methods in routing protocols. Several protocols [23], [24] proposed a routing protocol based on the cuckoo search algorithm for MANETs. ACO-LR-AOMDV [25] (ACO link reliable AOMDV) used an ant colony optimization (ACO) based link reliable (LR) for ad hoc on demand multipath distance vector (AOMDV) routing. The optimal path is selected based on hop count and minimum value of the Path-Link Quality Estimator (P-LQE), which has been integrated into the pheromone computation of the path. This solution may integrate different constraints. However, they are more complex and may require huge computational capacities.

According to this literature review, the routing protocols that have been proposed to improve the reliability of data transmission and the efficiency of routing by choosing the best paths based on one or multiple metrics, while some solutions employ various bio-inspired methods. Indeed, combining more than one constraint provides better results, but we should note that increasing the number of constraints will lead to complex calculations. Another point is that most of the works evaluate their solutions only based on the RWP mobility model due to its simplicity, but we have seen the importance of using a realistic model, such as the Manhattan model.

# 3 LQCA-ue Protocol

LQCA-ue is a reactive multi-path routing protocol that selects efficient paths to achieve objectives, ensure link quality and stability in the presence of noise and obstacles, maintain paths for as long as possible, and deliver data faster and more reliably. Our protocol evaluates paths in order to select the optimal path based on a fitness function that combines a quality function (SNR) and a stability function. This section explains how to discover, select, and maintain multiple paths.

## 3.1 Problem Formulation

A MANET is a collection of nodes connected by wireless links. It is represented by an undirected graph $G = (N, L)$ where "$N$" represents the set of nodes, and "$L$" represents the set of bidirectional links. The distance between two nodes $n_i$ and $n_j$ at given instance t is defined by:

$$Dest(i,j)(t) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

$d_{max}$ : Maximum distance between node $i$ and $j$ (known as the range).

SNR (Signal-to-noise ratio) is defined as the ratio of signal power to noise power and is usually expressed in decibels (dB), where $s$ represents the sender node and $r$ the receiver node, measured as follows:

$$SNR\ (s,r)(t) = \frac{P_{Signal}(s,r)(t)}{P_{Noise}\ (s,r)(t)} \quad (2)$$

## 3.2 Proposed evaluation functions

**Quality function (Signal to Noise Ratio).**
We simply choose the SNR as the quality function, which is a physical estimator. We have chosen it because:

- Fast, read directly from the physical layer, and represent the real-time state on the channel.

- Simple, as it doesn't require any complex calculation or storage.
- More precise than RSSI, as it takes into consideration the noise rate.

**Stability function.**
Protocols based on node mobility utilize certain criteria inherent to node mobility, such as their coordinates, movement directions, or speeds. We use the coordinates of the node for our protocol to observe the mobility behavior of nodes. To determine the link stability between two nodes *i* and *j*, nodes periodically exchange a Hello message k containing information about their position. Based on this information, when node *j* receives the message, node *j* calculates the distance separating itself from node *i*. We use the coefficient of variation, based on the standard deviation.

$ML_{i,j}$ is the average of *n* latest distance observed between node *i* and *j*:

$$ML_{\,i,j}\;(t) \;=\; \frac{\sum_{t=t1}^{n} Dest(i,j)(t)}{n}$$

$VL_{i,j}$ is the variance of the distances of link between node *i* and *j*, defined as:

$$VL_{\,i,j}\;(t) = \frac{1}{n}\sum_{t=t1}^{n}(Dest(i,j)(t) - \;ML_{\,i,j}\;(t))^2$$

The standard deviation is the most commonly used data dispersion measurement parameter, given by:

$$SDL_{\,i,j}\;(t) = \;\sqrt{VL_{\,i,j}\;(t)}$$

Finally, the stability function of a link (node *i* and *j*):

$$FSL_{\,i,j}(t) \;=\; \frac{ML_{\,i,j}\;(t)}{SDL_{\,i,j}\;(t)n} \tag{3}$$

The cost function stability of path *p* at time *t*, denoted by $FSP_p(t)$ is the maximum link stability costs of links constituting the path *s,d.*

$$FSP_{\,i,j}(t) = Max\;(FSL_{\,i,j}(t)) \tag{4}$$

**Fitness function**
In order to select the optimal path based on link stability and link quality. We propose a fitness function ffp (t) of path p (from node s to node d) at time t, defined by combining the energy cost function and the path cost function stability, defined as:

$$FF_{\,p}(t) = \;\alpha\,.FSP_{\,i,j}(t) + \;\beta.SNR_{\,s,d}(t)\;,\;\text{ with } \alpha+\beta\,=1 \tag{5}$$

### 3.3 Routing Discovery Process (Multi-path)

LQCA-ue, just like any reactive protocol, is based on three processes: discovery, path selection, and maintenance. It verifies the connectivity between nodes by sending a periodic Hello message.

**Neighbor Table Construction.**
Each node has neighbors that represent the adjacent nodes. In order to determine a neighbor's set, the network uses the Hello message and the Neighbor table to store information about them. Taking $i$ as a node that participates in active communication or wants to discover its neighbors, it sends a periodic Hello message containing information about its position. A node $j$ receives the message and calculates the distance between $i$ and $j$, and stores it in the neighbor table.

If a Hello packet from the same sender $i$ is not received within a certain period, this indicates that the sender has moved away and the link is down. Therefore, node $j$ removes it from the neighbor table, and the routing table is updated by removing all paths passing through node $i$.

**Table 1.** neighbors table structure of node i.

| | | | |
|---|---|---|---|
| $ID_{j1}$ , $Dest(i, j1)$ | $ID_{j2}$ , $Dest(i, j2)$ | ………………… | $ID_k$ , $Dest(i, k)$ |

**Route Request Process**
When a source node wants to send data to a destination node, and it doesn't have any valid path, the source node initiates a route discovery process by broadcasting a Route Request (RREQ) message to all its neighbors. First, each intermediate node receives an RREQ, then ensures that the received RREQ is not a duplicate to avoid routing loops. Otherwise, RREQ will be deleted. Secondly, it checks their routing tables for any valid paths to the destination. If the case, it will reply by sending a Route Reply (RREP) message; else, it will calculate both stability and quality functions, then broadcast the RREQ message to all its neighbors' nodes to find the destination. Once the destination node receives the first RREQ, it adds this path to its routing table and sends a Route Reply (RREP) message.

**Table 2.** RREQ message format.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| @Src | @Dest | BroadcastID | Src_SeqN | Dest_seqN | Hop_count | $FSP$ | SNR |

**Routing Reply process**
When the destination node receives the first RREQ, it calculates the path cost (formula 6) and saves the value in its routing table, then it generates a Route Reply (RREP) message and sends it back to the source. The RREP passes through the reverse path, passing by intermediate nodes (intermediate nodes will add the path to the destination) until it reaches the source node.

Once the source node receives the first RREP, it will wait for a given *RREP-Timer* period to receive additional RREPs before selecting the best path.

**Table 3.** RREP message format.

| | | | | | | |
|---|---|---|---|---|---|---|
| @Src | @Dest | Dest_seqN | Hop_count | Lifetime | Hop_count | *FF* |

**Route Maintenance Process**

Error detection is initiated when a link failure occurs between two nodes. When a node detects a failure on a link in an active path, it sends an RERR (Route Error) message to the source passing through the reverse path to announce that the path is broken. Upon receiving an RERR message, the source node removes the path from its table and looks for an alternative path to the destination node if one is available. If no alternative path is found, it initiates a route discovery to resume data transmission.

**Multi-Path Selection Process**

Our multipath selection sorts all discovered paths between a source node *s* and a destination node *d* by the descending value of $ff_p(t)$. The path with the maximum value of $ff_p(t)$ is chosen to forward the data packets.

**Table 4.** Algorithm of the multipath selection process.

| **Algorithm of path selection** |
|---|
| **If** *d* receive first RREP **then**<br>    Save the path *p*<br>    Start *RREP-Timer*<br>**Else** *save* the path *p*<br>**When** *RREP-Timer* expires<br>    Sort all the found paths in descending order by $ff_p$ value<br>    Select the first path to send data packets<br>**End;**<br>**If** *d* receive RERR of any path *x* **then**<br>    Remove the path from the routing table<br>    **If** *x* is the best path **then**<br>        **If** other paths exist **then** select the best path based on $ff_p$ value and send data<br>        E**lse**<br>            Stop sending data packets<br>            Launch a new discovery process<br>        **Endif;**<br>    **Endif;** |

## 4 Performance evaluation of LQCA-ue

In this section, we present the performance evaluation and the simulation results of the LQCA-ue routing protocol. We describe the simulation environment, where we use four mobility models: RWP (Random Waypoint), Manhattan Grid, and SMOOTH mobility. Then we present the performance metrics used to evaluate our protocol. Finally, we discuss the obtained results and the performance of our protocol compared to AOMDV (ad hoc on-demand multipath distance vector) [26].

### 4.1 Evaluation Parameters

We evaluate two performance metrics: PDR and overhead.

- The packet delivery ratio (PDR) is the ratio of data packets successfully received by the destination node over those sent by the source node.
- Overhead is the total number of control packets generated during the simulation.

### 4.2 Performance Environment

We have implemented LQCA-ue using Python. As our protocol is designed for urban areas, we have evaluated our protocol in four different mobility models:

- Random Waypoint (RWP): the simplest and most commonly used model where all movement is randomized, from the initial position of nodes, the movement direction and speed of each node, and the pause time. There are some parameters like *Vmin* and *Vmax* representing the minimum and maximum speed, respectively.
- Random Walk (RW): similar to RWP (random mobility). However, each node moves in a direction with a specific speed for a specific time *t* .
- Manhattan Mobility Model: modelize the movement in a city. It consists of several horizontal and vertical lines forming a grid where nodes can move along the vertical and horizontal roads (streets).
- Obstacle Mobility Model: Another geographic constraint in mobility modeling includes the obstacles in the simulation field. The obstacles not only affect the movement behavior of mobile nodes but also impact the way radio propagates.

### 4.3 Performance evaluation

The main objective of these simulations is to determine the efficiency of our protocol by comparing it with the AOMDV protocol under different mobility models. The table table 5 summarizes the simulation parameters used. We assumed also that all mobile nodes in the network are equipped with IEEE wireless communication interfaces. we have the Manhattan model, at each intersection, there is a 0.25 probability of turning left and a 0.25 probability of turning right.

**Table 5.** Simulation Parameters.

| | |
|---|---|
| Simulation | Python |
| Routing protocol | LQCA-ue and AOMDV |
| Simulation time | 150s |

| | |
|---|---|
| Number of nodes | 15/30/60/100 |
| Terrain range | 800 x 600 m |
| Transmition range | 170 m |
| Maximal speed | 10 m/s |
| Minimal speed | 1 m/s |

**PDR results**

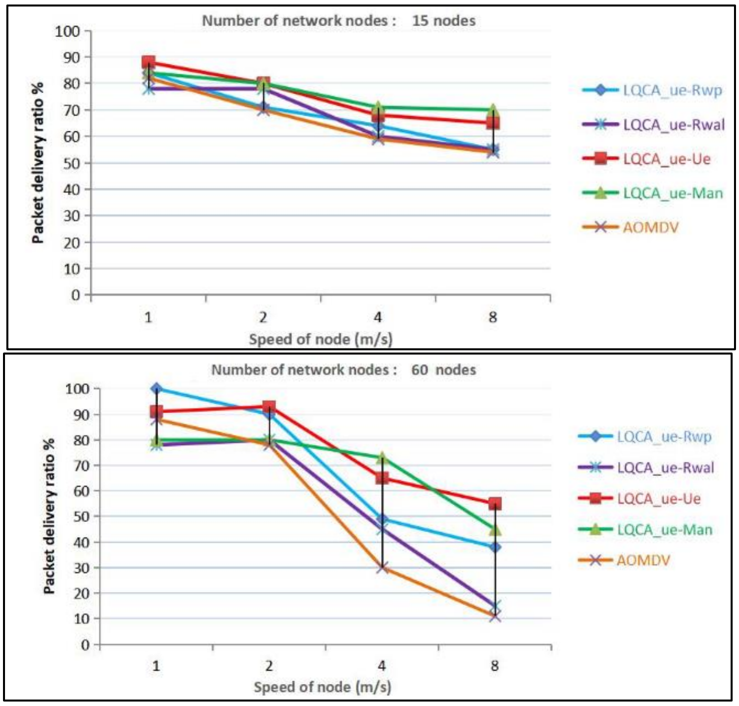


**Fig. 1.** PDR rate vs node speed for 15 and 60 nodes

Figure 1 shows the packet delivery ratio (PDR) in different mobility models: Random Waypoint, Random Walk, Obstacle, and Manhattan Grid for our protocol and AOMDV. We can observe that the number of successfully received packets by LQCA-ue is higher than that of AOMDV. LQCA-ue selects the best paths in terms of link quality and stability, which reduces link breaks and ensures good reliability. PDR in the first image (15 nodes) shows that LQCA-ue is better than AOMDV by 7% for low speed. However, as the speed increases, we can see that LQCA-ue gives better improvement by 11% for an 8m/s speed.

In the second figure, we can observe that the PDR drops significantly when the speed increases, as nodes quickly move out of the transmission range, which means more frequent link failures. Furthermore, our protocol in a medium-density network (60 nodes) increases the PDR compared to AMODV by 35%, especially for the Manhattan model because our protocol is more adapted to the urban area.

**The Overhead's results**

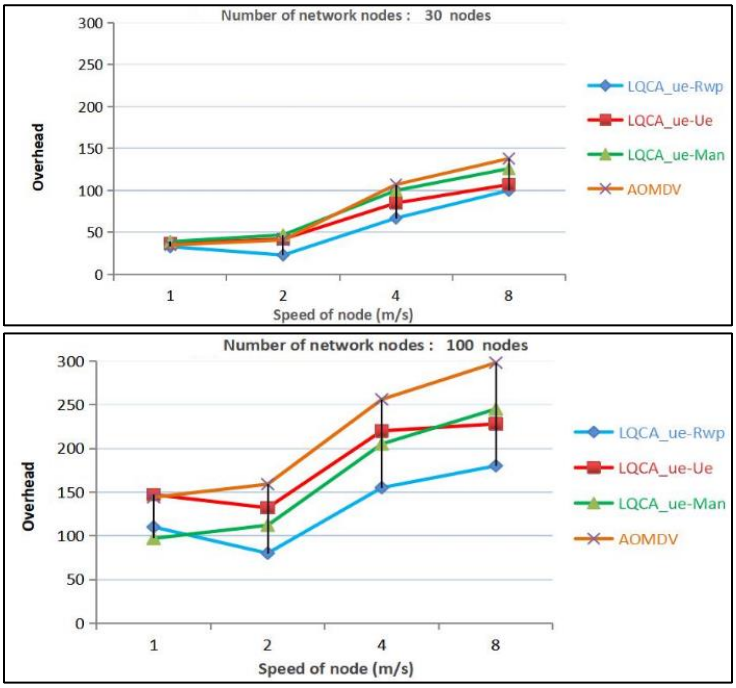


**Fig. 2.** The overhead vs node speed for 30 and 100 nodes

The number of control packets (Overhead) is represented in Figure 2 for a network density of 30 and 100 nodes. The results show that LQCA-ua protocol reduces the control overhead (in most scenarios). In the first image, all protocols have approximately the same overhead because, at low speeds, we may have very few link failures. However, as the speed increases, we can notice considerable improvement by reducing overhead by 45% for RWP and 20% for Manhattan. In the second image (100 nodes), our protocol outperforms AOMDV in all speeds and reduces overhead by 40% at low speeds and up to 50% for high speeds. Our protocol evaluates the path based on quality and stability in an efficient manner, which increases the path lifetime and reduces the number of discovery processes.

We notice that RWP performs better. However, in Manhattan and the Obstacle mobility model, we have similar results because both of them have environmental effects that affect the signal and the mobility constraints of nodes in urban environments.

# 5 Conclusion

For MANET, the urban environment has particular characteristics that can affect the network due to the presence of obstacles that restrict node movement and significantly impact signal propagation. Furthermore, it contains various noise sources. Indeed, it's important to take these factors into designing an efficient routing protocol (especially the signal quality constraint). In this context, we introduce LQCA-ua, a new multi-path routing protocol for ad hoc networks. Our protocol prefers link quality and stability while selecting paths to improve network performance. We evaluated our LQCA-ua protocol in four mobility models: Random Waypoint and Random Walk for open spaces, Manhattan Grid for realistic urban mobility, and Obstacle for indoor-like mobility. Our LQCA-ua protocol outperformed the AOMDV protocol in terms of transmission reliability and control packets.

In our future works, we will try to integrate the energy constraint in our approach and integrate a mechanism to predict the failure and avoid it before it happens, not just to react to it.

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