Selection of Stable Paths in the MANET Network

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***Abstract* —**With the deployment of MANET mobile networks, the failure link is problematic. Due to the characteristics of ad hoc mobile networks, the failure link is mainly due to the node mobility, energy consumption of the batteries and the radio link quality. Failure link causes loss of data packets and more traffic control for path repair. In this paper we propose an analytical model of the multi-criteria cost function for the selection of stable paths. This function is defined based on residual energy, degree of mobility, traffic rate and link quality. We have integrated this solution into the reactive multipath protocol AOMDV. Finally, the results of simulation show that our approach offers good performances and answers the concern of failure link.

Index Terms—Manet, AOMDV, failure link, energy, mobility, link quality, traffic load.

I. Introduction

In order to control and regulate the distribution of traffic in an ad hoc mobile network, we use traffic engineering (TE). The TE brings together all routing control mechanisms to optimize the use of network resources, while guaranteeing QoS (delays, life time).

The considerable increase in traffic volumes and new constraints in terms of quality of service (QoS) require additional mechanisms to ensure a longer life of the network with better distribution and load balancing.

Given the special characteristics of mobile networks MANET (mobility, variable and unpredictable topology, energy consumption, radio link quality...) paths are unstable.

In this paper we propose selection of stable paths with reliable links for routing traffic in mobile networks MANET. Our goal is to maximize the amount of traffic that can pass in this type of network and extend the network lifetime.

In the next section we present the stable path-based routing protocols. Section 3 presents our approach with an overview of our analytical model and its implementation. Section 4 is dedicated to experimentation and results discussion. Finally, Section 5 closes our study with a conclusion and perspective.

II. Related Works

In order to improve the performance of a routing protocol in ad hoc mobile networks, it is necessary to reduce the number of failure link. The failure link in the path is mainly due to the instability of the links. Therefore, during the road discovery phase, the routing protocol must choose the best path in terms of stability. The main research work proposed to determine the link stability in an ad hoc mobile network is based on the estimation of signal strength or the load of nodes or the nodes mobility or the residual energy of the nodes

The authors [1] propose the IRU (Interference-aware Resource Usage) metric as a measure for capturing the effect of inter-flux interference and differences in transmission rates as well as loss rates on the wireless link. However, the measurement of the interference of the neighbours existing on the same link is considered similar, which is not correct because the interference signal depends on the distance between the nodes.

The authors [2] propose the "interference" metric related to link traffic load to indicate the effect of traffic load on neighbouring nodes. Hello messages are used to obtain information about the delay of an interface by counting the number of packets existing in the buffer of the interface. This approach provides information about the traffic load around the Link.

In article [3], the authors propose a method for the prediction of the availability of the link based on signal strength. The nodes estimate the link failure time and prevents the other nodes from any link failure in the selected path. On the basis of this information, the repair of the local path or the new path discovery will be initiated before the path is broken.

In order to take into account the quality of the signal received during the routing process, the authors [4] propose a cross-layer approach by creating cooperation between the network layer and the physical layer. This approach uses the Signal to Interference plus Noise Ratio (SINR) metric. The SINR considers multi-path propagation and interference. The authors also use the RSSI (Received Signal Strength Indication) parameter. These two parameters are provided by the physical layer and are used by the network layer and the MAC layer. The route discovery process is based on the SINR metric which aims to provide stable links with minimal interference. Each node existing on the path between source and destination stores in its routing table the values of the SINR and RSSI. The RSSI parameter is used to minimize the transmission power of data packets in the Mac layer. The approach makes it possible, on the one hand, to establish the paths with stable links and, on

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the other hand, allows the energy gain by minimizing the transmission power of the data packets.

Mobility is one of the strengths of mobile networks, but this mobility often leads to the link failure on a path selected for the routing of data packets. In [5], the authors propose a routing protocol that initiates the road discovery with the failure link prediction on the path used. The approach is based on an analytical method that predicts the remaining lifespan of the link. The approach estimates the future position of a node according to its current position, speed of movement and direction.

To calculate the reliability of a link as a function of the distance between the nodes based on the nodes mobility (inter-node distance). [6] uses a Markov chain that describes the evolution of the inter-node distance. This solution requires knowledge of the position of all nodes at all times. The article [7] proposes an adaptation of the previous approach to calculate the stability of link between two nodes that move according to the Semi-Markov Smooth (SMS) mobility model. It takes into account propagation channel errors by introducing the notion of effective transmission range (ETR). This is defined as the maximum distance for which the probability that a packet is not altered by channel errors is large. This scope definition does not take into account the number of MAC retransmissions. As a result, it is appropriate only when there is no retransmission.

Similarly, the authors [8] propose an efficient routing mechanism with path prediction with reliable links. They collect paths from the source to the destination. Each node with GPS (Global Positioning System) predicts the next expected location. With this mechanism, the source node can decide the selection of the path with the longest connection time.

The authors [9] propose the calculation of the integrated data transmission cost (IDTC) to quantitatively measure the communication quality of the links. In this cost, they integrate node mobility, channel interference and cognitive nodes, workload on a specified channel, and the distance between the relay and the destination node. Then they propose a consistent routing and channel assignment protocol (J-SRCA), based on mobility prediction for network throughput maximization. In J-SRCA, each hop-hop link is assigned simultaneously to an interference avoidance channel during a route configuration.

The Lifetime Prediction Routing (LPR) have been proposed in [10], The LPR uses energy lifetime prediction. The objective of this routing protocol is to extend the service life of mobile ad hoc in a dynamic topology. This protocol favors the path whose lifetime is the largest one.

The authors of the article [11] exploit the residual energy of the nodes to be selected and classify the paths according to the level of energy. This approach conserves the residual energy of the nodes and balances the energy consumed on multiple paths.

[12] proposes a dynamic probabilistic broadcast for route discovery (DPBRD), which tries to reduce the replicated copies of control messages to save energy and avoid breaking links. This method determines the forward probability by consider extended area and hop density to forwards request messages to its neighbours.

III. Motivation

The set of routing protocols is responsible for establishing the path between a source and a destination and maintaining these paths. However repairing a path, because failure link on this path, is costly (packet loss, overhead count, end-to-end delays). Due to the characteristics of the mobile ad hoc networks, a failure link can be triggered by the node mobility of the path or the exhaustion of the node's battery or the poor link quality (channel status) between two nodes of the path. A node can deduce the state of the channel with a neighbour as a function of the power of the received signal. The link stability is estimated from this measure and the link quality is deduced according to the perceived interference rate.

In the same way, the knowledge of the mobility degree of the nodes can deduce the links lifetime. And estimating the residual energy of a node can prevent the node death. A high rate of traffic passing through a node triggers a bottleneck (congestion) and subsequently loss of data packet. The estimate of this rate helps us in the load balancing mechanism

Therefore, we propose stable paths selection with reliable links. The goal is to traffic load balancing, maximize the rate of data received, extend the network life. We define a path selection cost function according to the following parameters:

- Residual energy of the nodes
- Mobility degre of the nodes
- Traffic oad of the node or the rate of traffic passing through this node
- Link quality between two nodes

IV. Proposed Approach

In the following, we propose the analytical model for the computation of the stability of a path for the MANET networks according to the metrics defined above.

The calculation is done in three steps:

- Calculation at the node
- Calculation at the level of a link between two neighbouring nodes
- Calculation at the level of a path between a source s and a destination d (set of nodes or contiguous links)

A. Analytical Model

Let a path P_j among a set of paths P between a source s and a destination d, the cost of selecting the path P_j (Cost of Path) $CP(P_j)$ is formulated as follows:

$$CP(P_j) = \alpha * R_{RE(Pj)} + \beta * R_{MD(Pj)} + \lambda * R_{TL(Pj)} + \gamma * R_{LQ(Pj)} \quad (1)$$

With $\alpha + \beta + \lambda + \gamma = 1$

$R_{RE(Pj)}$: Rate of Residual Energy of the path

$R_{MD(Pj)}$: Rate of node Mobility Degree

$R_{TL(Pj)}$: Rate of Traffic Load transiting via the path nodes

$R_{LQ(Pj)}$: Rate of path Links Quality

In the following, we detail the formulation and calculation of each parameter at the level of the node, the link and the path.

B. Energy

Let RE(n_i) Residual energy of node i. The minimum value of the residual energy of the nodes on the path Pk is:

$$RE(P_k) = \text{Min}\,[RE(n_i)]_{1\leq i\leq N} \quad (2)$$

With N number of nodes of path Pk

The residual energy on the path (Pj) to be selected is as follows:

$$RE(Pj) = \text{Max}\,[RE(P_k)]_{1\leq k\leq M} \quad (3)$$

With M number of possible paths between source and destination

The residual energy rate on the path (Pj) to be selected is as follows:

$$R_{RE(Pj)} = RE(Pj) / \sum RE(P_k)_{1\leq k\leq M} \quad (4)$$

C. Mobility

Based on the study [13], we define the degree of mobility of a node in a time interval [t, t + Δt] as follows:

$$MD(n_i) = \alpha \frac{NOut}{Nca} + (1-\alpha)\frac{NIn}{Nca} \quad (5)$$

With:

NOut: number of nodes that have left the node's coverage area and in [t, t + Δt]

Nin; Number of nodes that have joined the node's coverage area and in [t, t + Δt]

Nca: number of nodes in the coverage area of ni (neighbours) at time t

α: Mobility coefficient, it takes the value between 0 and 1. It is equal 0.5 According to [13].

The degree of average mobility on a path is formulated as follows:

$$MD(P_j) = \frac{1}{N}\sum_{i=1}^{N} MD(n_i) \quad (6)$$

With N is the number of nodes participating in the path.

The mobility rate of the path is represented by:

$$R_{MD(pj)} = Min\left[MD(P_k)\right]_{1\leq k\leq M} \quad (7)$$

With M number of possible paths between source and destination

D. Load of Node

The load of a node represents the number of traffic passing through this node. Let TL(n_i) Traffic Load transiting via the node i. The maximum value of the traffic load on the path Pk is:

$$TL(P_k) = \text{Max}\,[TL(n_i)]_{1\leq i\leq N} \quad (8)$$

With N number of nodes of path Pk

The traffic load on the path (Pj) to be selected is as follows:

$$TL(Pj) = \text{Min}\,[TL(P_k)]_{1\leq k\leq M} \quad (9)$$

With M number of possible paths between source and destination.

And the calculation of the traffic load rate on the path (Pj) to be selected is as follows:

$$R_{TL(Pj)} = TL(Pj) / \sum TL(P_k)_{1\leq k\leq M} \quad (10)$$

E. Link Quality

The link quality ratio of the signal strength to the noise:

$$QL(ni, ni+1) = SINR(ni, ni+1) / SE(ni) \quad (11)$$

With

$$SINR(ni, ni+1) = SR(ni+1) * \text{Noise} \quad (12)$$

$LQ(n_i,n_{i+1})$: Link Quality between two nodes n_i and n_{i+1}

$SINR\ (n_i,n_{i+1})$: Signal to Interference Noise Ratio

$SE\ (n_i)$: Signal Strength Emitted of the node

$SR(n_{i+1})$: Signal Strength Received from the node

Noise: Signal noise

Let LQ(l_i) link quality (li) between two nodes. The minimum value of the link quality on the path Pk is:

$$LQ(P_k) = \text{Min}\,[LQ(l_i)]_{1\leq i\leq N} \quad (13)$$

With N number of links of path Pk

The link quality on the path (Pj) to be selected is as follows:

$$LQ(Pj) = \text{Max}\,[LQ(P_k)]_{1\leq k\leq M} \quad (14)$$

With M number of possible paths between source and destination

The rate of link quality on the path (Pj) to be selected is as follows:

$$R_{LQ(Pj)} = LQ(Pj) / \sum LQ(P_k)_{1\leq k\leq M} \quad (15)$$

F. The Path Cost Function

Following the analytical model, we formulate the path cost function as follows:

$$CP(P_j) = \alpha * R_{RE(Pj)} + \beta * R_{MD(Pj)} + \lambda * R_{TL(Pj)} + \gamma * R_{LQ(Pj)} \quad (1)$$

With:

$$R_{RE(Pj)} = RE(Pj) / \sum RE(P_k)_{1\leq k\leq M} \quad (4)$$

$$R_{MD(pj)} = Min\left[MD(P_k)\right]_{1\leq k\leq M} \quad (7)$$

$$R_{TL(Pj)} = TL(P_j) / \sum TL(P_k)_{1\leq k\leq M} \quad (10)$$

$$R_{LQ(Pj)} = LQ(P_j) / \sum LQ(P_k)_{1\leq k\leq M} \quad (15)$$

α, β, λ and γ: are weighting factors depending on whether we want to focus on nodes with a high energy, or mobility and node load low, or good quality of the signal.

Because the mobility and load of the nodes affect the quality of the link, the three parameters complement each other. Therefore we assign priority to the energy rate, followed by the quality of the link, the mobility and the load of the traffic will have the same weighting.

$$\begin{cases} \alpha+\beta+\lambda+\gamma=1 \\ and \\ \beta+\lambda+\gamma=\alpha \\ and \\ \beta=\lambda \end{cases} \tag{16}$$

By applying a series of simulations, the following weightingvalues were used:

α=0.5 , β=0.1 , λ=0.1 and γ=0.3

This choice implies that we give priority to the paths that have the best energy rate (α = 0.5) and the best link quality link (γ = 0.3), we consider the mobility and the load with a weight of 0, 1.

G. Implementation of the Proposed Approach

We apply our function for the selection of stable path in the multipath reactive protocol AOMDV. We define the RREQ frame and the RREP frame as follows:

Type	Reversed	Last hop	Hop count	Min RE	*Max MD*	*Max TL*	*Min LQ*
RREQ ID							
Destination IP Address							
Destination Sequence Number							
Originator IP Address							
Originator Sequence Number							

Fig. 1. RREQ trame

During road discovery, the update of the RREQ frame is done as follows:

Begin
At each node
if $RE(n_i)$<min RE then min RE←$RE(n_i)$
if $MD(n_i)$>max MD then max MD←$MD(n_i)$
if $TL(n_i)$>max TL then max TL←$TL(n_i)$
if $LQ(n_i)$<min LQ then min LQ←$QL(n_i)$
End.

The new format of the RREP trame is as follows:

Type	ACK	Last hop	Hop count	R_{ER}	R_{MD}	R_{TL}	R_{LQ}
Destination IP Address							
Destination Sequence Number							
Originator IP Address							
Lifetime							

Fig. 2. Trame de RREP trame

Upon receipt of the trame RREP the source selects the path with the best rate. If two paths have the same rate, then the source selects the path with the minimum of hops

V. Simulation Results

We first implemented the load balancing mechanism in the AOMDV multipath protocol (which we named LB-AOMDV), then we implemented the LPR technique [10] in the AOMDV protocol (which we named LPR-AOMDV)

We conducted extensive simulations, using NS2 [14], to determine the effectiveness of our routing protocol called 4P-AOMDV. We compare it to the LPR-AOMDV and LB-AOMDV

TABLE I: Simulation Parameters

Parameter	Value
Simulation time	500 s
Simulation area	900 x 900 m2
Radio range	250m
Number of nodes	20, 40, 60, 80, 100… 160
Velocity	(4m/s, …, 20m/s)
Pause time	5 s
Initial energy	100 Joule
Tx power, Rx power, Idle power	0.4, 0.3, 1.0 (Watt)
Routing protocols	LB-AOMDV, LPR-AOMDV, 4P-AOMDV
MAC protocol	IEEE 802.11

Fig. 3 shows the energy consumed by the three routing protocols as a function of the number of nodes in the network. We find that both protocols with a specific function path selection cost consume less energy than the LB-AOMDV protocol.

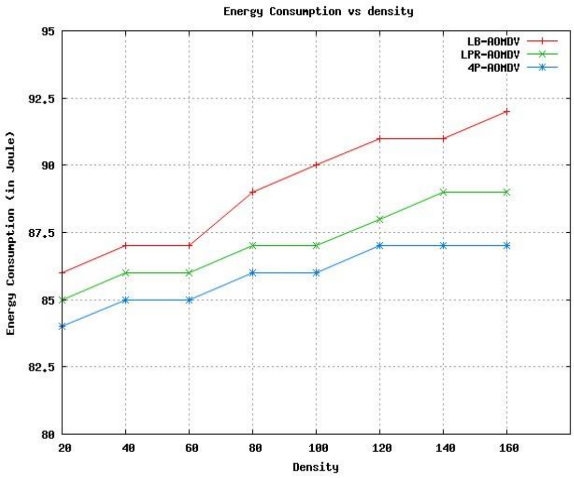

Fig. 3. Energy consumption vs density

The packet delivery rate is an important parameter in the comparison of routing protocols. This metric characterizes the efficiency of the routing protocol.

We notice (Fig. 4) that the performance of the three protocols in terms of data packet delivery decreases as the number of nodes increases. This result is related to increased road loads and collisions that occur. However, the packet delivery rate of the 4P-AOMDV protocol is more important than LPR-AOMDV.

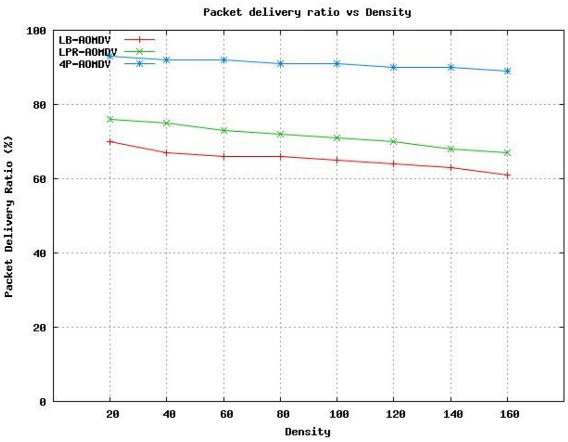

Fig. 4. Packet delivery ratio vs density

The network lifetime is an important metric for evaluating protocols in mobile networks. In the following we analyze the time required for the death of the first node in the network (Fig. 5) and the time required for the death of the last node which guaranteed network connectivity (Fig. 6).

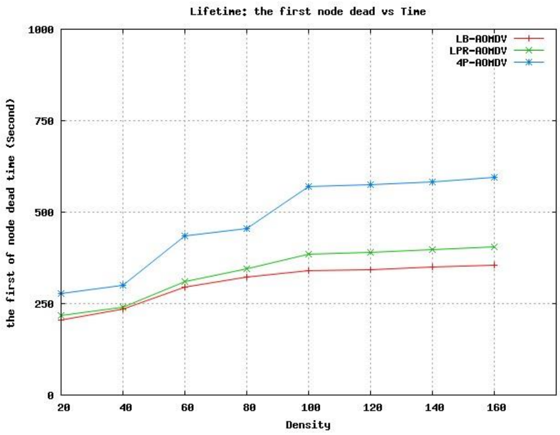

Fig. 5. Lifetime: The first node dead vs densit

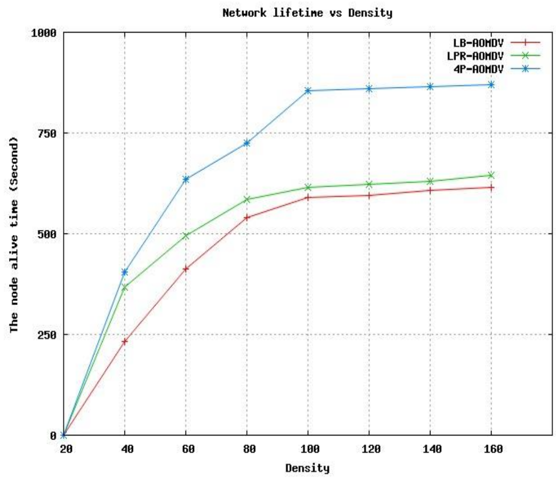

Fig. 6. Network lifetime vs density

We note that 4P-AOMDV gives better performance than LPR-AOMDV. The LB-AOMDV protocol is based on the number of hops between source and destination. The LPR-AOMDV protocol uses the energy metric when selecting paths. However, our 4P-AOMDV approach take into account the metric of energy and link quality in addition to mobility and traffic load. This difference makes the path selection cost function (4P-AOMDV) more accurate and efficient.

Load balancing in LB-AOMDV and LPR-AOMDV generates approximately the same node lifetimes. Our 4P-AOMDV approach significantly extends the network lifetime.

The overhead metric represents the control traffic generated by the routing protocol to compute and maintain paths. This is an important metric in the comparison of routing protocols. It is often used to indicate the ability of a protocol to function in congested networks and/or with limited bandwidth.

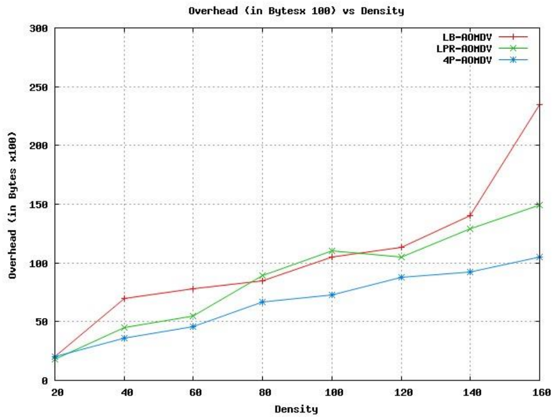

Fig. 7. Overheads vs density

Fig. 7 shows the overheads generated by the routing protocols as a function of the density of the network. We notice that the overhead grows according to the number of nodes, for the three routing protocols. Overhead packets are generated for maintaining paths. The LB-AOMDV and LPR-AOMDV protocols undergo path breaks more frequently, so they generate overheads for maintaining paths. The 4P-AOMDV protocol behavior is better. Path breaks are less frequent, therefore less control traffic to generate. This performance comes down to the function of the path selection cost, which considers link quality, mobility and energy when selecting paths.

VI. Conclusion

In this paper, we proposed a multi-criteria function for calculation of the path selection cost in the MANET networks. This function has been implemented in the reactive multipath protocol AOMDV which we have called 4P-AOMDV. The goal is to ensure, during the path discovery, the selection of stable and reliable paths. Selection is based on four criteria: residual energy, mobility, traffic load and radio link quality. The aim of this work is to avoid the breaks in the frequent links which cause the loss of data packets and generates more control packets (overhead) for the paths maintenance.

The proposed 4P-AOMDV protocol is validated by simulation by evaluating its performance via the NS2 network simulator. The simulation results show that 4P-AOMDV offers better performance in terms of received packet rate, network lifetime and overheads. We propose, in future work, the integration of the cost function in the multicast routing protocol (MAODV) in order to improve its performance.

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