MSAR: A Metric Self-Adaptive Routing Model for Mobile Ad Hoc Networks

Tran The Son (*), (**), Hoa Le-Minh (*), Nauman Aslam (*)
(*) Faculty of Engineering and Environment
Northumbria University, Newcastle Upon Tyne, United Kingdom, NE1 8ST
{hoa.le-minh, nauman.aslam}@northumbria.ac.uk
(**) Korea – Vietnam Friendship IT College, Danang, Vietnam
trantheson@mic.gov.vn

Abstract- **This paper proposes a metric self-adaptive routing scheme for Mobile Ad Hoc Networks (MANET). By applying the proposed model, each node is able to detect whether the mobility states of the network is relatively static or mobile without the support of the Global Positioning System (GPS). The mobility state detection model is designed based on an indicator named MSI (for proactive routing) or GMSI (for reactive routing) computed at each node. Based on MSI/GMSI, an adaptive algorithm is then designed to employ the appropriate routing metric, i.e., either Expected Transmission Count (ETX) or Path encounter Rate (PER), for each detected state in order to achieve the optimum routing performance for different network conditions (i.e., static or mobile).**

Keywords- **Mobile ad hoc networks; metric self-adaptive routing; ETX; PER**

1. Introduction

Though MANET has been developed for the past decade, routing in MANET is still facing to many challenges caused by the random movements of nodes and limited transmission capacity of mobile devices. The network topology might change as time and space evolve and the established route for sending data could be broken when the intermediate node(s) move out of the communication range of the others [1]. Routing performance will become very poor if the mobility of nodes is high. To achieve a high routing efficiency, routing protocols therefore should be adaptive to the changes of MANET.

In real a scenario, nodes in a MANET might not move all the time. It could be absolutely stationary (e.g., people are sitting in a meeting/theatre); or relatively stationary (e.g., people are sitting on a coach/train). That introduces a complex mobility pattern of MANET including absolutely/relatively stationary or mobile.

Unfortunately, current routing metrics proposed for MANET produce an optimal routing performance for a specific condition, either static or mobile, not for all network mobility conditions. For example, Expected Transmission Count (ETX) [2] or Expected Transmission Time (ETT) metric [3] helps nodes find the highest throughput path for routing in static condition (all nodes are stationary). If the network is mobile, nodes have insufficient time to calculate ETX or ETT [2], [3], thus inducing an inaccurate routing decision. Such a routing decision causes a degradation of routing performance of MANET. Meanwhile, mobility metrics such as link expiration time metric [4], link duration metric [5], contact-based mobility metrics [6], mobility factor [7], and path encounter rate [8]) produce a best routing performance for mobile condition (nodes arbitrarily move in network area). If the network becomes static for some reason, those proposed mobility metrics do not have any advantages. Even they take a higher complexity than simple hop-count metric and others.

It is generally acknowledged that designing an *one-size-fit-all* metric for MANET routing is likely to be impossible [9] because of the unpredictable change of MANET topology. However, that can be achieved by adaptively applying a proper metric for each network state (i.e., absolutely static, relatively static or mobile). This inspires the adaptive routing model proposed in this paper. The key contributions of this paper are as follows

- Proposing a model which allows each node to detect whether the mobility states of the network is static (including absolutely and relatively static) or mobile. The detection model is based on Mobility State Indicator (MSI) designed for proactive routing or Global MSI (GMSI) designed for reactive routing. MSI/GMSI is calculated at each node without the support of the GPS.
- Proposing Metric Self-Adaptive Routing (MSAR) model which enables nodes to adapt routing metrics (i.e., ETX, PER), to the network mobility states (i.e., static, mobile respectively) based on the detection above.

Related Work

Many adaptive unicast routing have been proposed in the literature to enable nodes to adapt to the unpredictable changes of MANET topology.

Cong Liu *et al.* [10] introduced a routing protocol named Adaptive Routing in Dynamic Ad Hoc Networks (AROD), which is seamless integration of existing routing models to adapt to node density and mobility pattern. Routing performance is presented as highly scalable and adaptable to different network scenarios.

To avoid packet loss due to link breakages, Lin *et al.* [11] presented an adaptive routing protocol named Adaptive Route Selection (ARSMA) under which a source node discovers multiple routes to the destination, one for primary, and the others for backup. When the primary route is broken, the source node tries to switch data from the primary route to one of the backup routes. As a result, the ARSMA enhances packet delivery ratio and reduces end-to-end delay of the network. However, the information of backup routes stored in the routing table could become stale due to the movement of nodes, which results in inaccurate routing decisions.

Fathy *et al.* [12] proposed an Adaptive Cross Layer Protocol (ACRP) using Fuzzy Inference System to adapt to the mobility and application types. The model has the ability to switch between routing modes, i.e., proactive and reactive, based on network mobility and traffic types. The achieved routing performance is shown as very stable and much enhanced compared to the routing performance of the Ad Hoc On-demand Distance Vector (AODV) protocol [13] and the Destination-Sequenced Distance Vector (DSDV) protocol [14] in different speeds and traffic loads. However, the ACRP faces a challenge related to synchronisation among nodes while switching between routing protocols and updating routing information for different types of routing.

From the same perspective, the authors in [15] proposed a Mobility Adaptive Hybrid Routing (MAHR) scheme to adapt to the mobility of the network. To detect the network mobility, every node uses Mobility Ratio (MR) metric which is calculated based on the duration of connected links to neighbours. When the MR value exceeds a given threshold, a node changes its operation mode to be proactive. This model has been implemented on AODV and achieved a better performance than the original AODV and Optimized Link State Routing (OLSR) protocol [16]. This approach also faces the same challenge as that of Fathy's model.

To take advantages of proactive and reactive without switching between two routing types, authors in [17] are based on Zone Routing Protocol (ZRP) [18] to develop a centralized adaptive hybrid routing (CAHR) mechanism for MANETs. Their model adapt to the frequent changes of zones' topology by periodically electing the key nodes. This helps to reduce the number of forwarding control messages and routing overhead over the network.

Another interesting approach for adapting to the mobility of the network which is proposed in [19] is to adjust the HELLO frequency based on the appearance rate of new neighbours in the neighbourhood table. This model named Turnover based Adaptive HELLO Protocol (TAP) relies on the fact that the more mobile a node is, the more frequently new neighbours appear. The HELLO frequency is adjusted to be higher if the number of new neighbours is high and vice versa. This solution helps nodes reduce the number of redundant HELLO messages while still ensuring a quick check neighbours' appearance and link availability.

To save the energy consumption at each node, the authors in [20] proposed a Hello Messaging Scheme named Adaptive Hello (AH) to adapt the HELLO frequency to the traffic demand. If a node has no packets to forward, it reduces the frequency of sending HELLO messages to neighbours for checking link availability. This model helps MANETs diminish the number of HELLO messages while still checking properly link availability to save energy consumption.

In MANET, congestion is one of the main causes for a poor routing performance [21], hence, awareness of and adapting to network congestion will allow nodes to improve routing performance. By monitoring the number of packets stored in the buffer, the Congestion Adaptive Routing Protocol (CRP) [21] can detect and classify congestion status whether it is free or likely to be congested or already congested. If the congestion is more likely to be occurred, nodes split their traffic over a "bypass" routes to diminish the congestion beforehand and balance the traffic load all over the network.

Another approach to improve routing performance is to determine the route request (RREQ) forwarding probability of a node based on its residual energy and energy drain rate proposed by authors in [22]. This model applies adaptive fuzzy logic system for energy-aware RREQ probability forwarding tuning, therefore their proposed model can maximize the network lifetime. However, applying an adaptive fuzzy logic system with reinforcement learning mechanism might increase the complexity at the network layer of a node.

It can be seen that none of above-mentioned protocols has concerned about the adaptation of routing metrics to the mobility states of the network as introduced in this paper.

The rest of this paper is structured as follows. Section 2 introduces MSI/GMSI used for detecting mobility state of the network. Section 3 proposed MSAR model to adapt routing metric to network mobility state for both proactive and reactive routing. Section 4 follows up by a comprehensive performance evaluation in different mobility models. Finally, Section 5 concludes the paper.

2. MSI Indicator and Analysis

A MANET is represented by graph $G(V, L)$, where V is a set of nodes, L is a set of links between pairs of nodes in the graph. A link $\{a, b\}$ from nodes a to node b appears when node b comes into the communication range of node a. Each node is equipped with a single radio with a fixed transmission range R.

2.1. Definitions

Definition 1 (Encounter) - Two nodes encounter each other when the distance between them becomes smaller than the communication range R [6]. The encounter e_{ab} between node a and node b is defined as:

$$e_{ab} = \{a, b, t, \Delta t\} \quad (1)$$

where t is the incident time of the encounter and Δt is the duration or lifetime of the encounter.

Definition 2 (Average Encounter Rate) - The Average Encounter Rate (AER) is the average number of *new* encounters experienced by each node in a duration T. Let $N_E(A)$ be the set of *new* encounters observed by node A

within duration T, the AER of node A can be calculated as follow [6]:

$$AER_A = \frac{|N_E(A)|}{T} \quad (2)$$

where $|N_E(A)|$ is the cardinality of set $N_E(A)$.

2.2. AER and Analysis

Constant Velocity

Assume that nodes are distributed uniformly with a given density λ and moving at an identical velocity v.

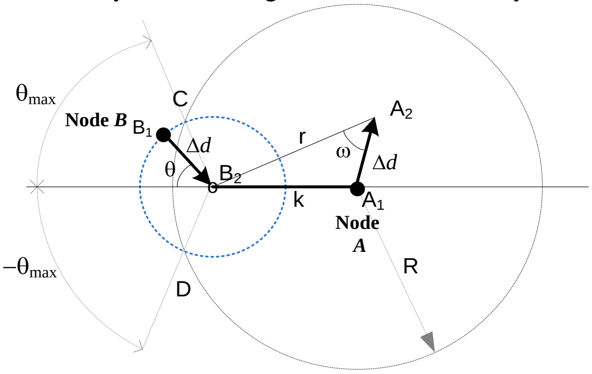

Fig. 1. AER analysis

Let r be the distance between two nodes after a duration T, r = A_2B_2, k be the segment A_1B_2; ω be the angle generated by the segments A_1A_2 and A_2B_2.

Let $P(r)$ be the probability that a new encounter appears in a duration T, the expected number of new encounters of node A (denoted $\mathbf{E}\,[N_E\,(A)]$) after duration T is estimated by

$$\mathbf{E}[N_E(A)] = \int_0^R 2\pi\lambda \times r \times P(r)dr \quad (3)$$

This paper uses the analysis proposed in the previous work [8] in which the AER of node i is identified as

$$AER_A = \frac{|N_E(A)|}{T} = \frac{2\lambda}{\pi}\psi_A(v) \quad (4)$$

where $\psi_A(v) = \frac{1}{T}\int_{r_{\min}}^{R}\int_{\omega_{\min}}^{\pi} r\theta_{\max} d\omega dr$; (5)

$$\omega_{\min} = \arccos\left(\frac{r^2 + 2R\Delta d - R^2}{2r\Delta d}\right); \quad (6)$$

$$\theta_{\max} = \arccos\left(\frac{R^2 - \Delta d^2 - k^2}{2k\Delta d}\right) \quad ; \quad (7)$$

$$\Delta d = v \times T\,. \quad (8)$$

$r_{\min}$ is chosen in (0, R - $2\Delta d$) such that node B is still recognised as a new encounter within duration T.

Random Velocity

In reality, the velocities of nodes are *not* constant and change randomly depending on nodes' mobility patterns. In such circumstances, the expected value of AER_A is derived from Eq. (4) as follows

$$\mathbf{E}[AER_A] = \mathbf{E}\left[\frac{2\lambda}{\pi}\psi_A(v)\right] = \frac{2\lambda}{\pi}\mathbf{E}\left[\psi_A(v)\right] \quad (9)$$

In most mobility models, the velocity v is uniformly distributed in [$v_{\min}$, $v_{\max}$], hence we have

$$\mathbf{E}[AER_A] = \frac{2\lambda}{\pi}\mathbf{E}\left[\psi_A(v)\right] = \frac{2\lambda}{\pi}\int_{v_{\min}}^{v_{\max}}\psi_A(v) \times P(v)dv \quad (10)$$

where $P\,(v)$ is the probability density function (pdf) of v.

$$P(v) = \frac{1}{v_{\max} - v_{\min}}, \qquad v_{\min} \le v \le v_{\max} \quad (11)$$

Thus, Eq. (10) can be re-written as

$$\mathbf{E}[AER_A] = \frac{2\lambda}{\pi}\frac{1}{(v_{\max} - v_{\min})}\int_{v_{\min}}^{v_{\max}}\psi_A(v)dv \quad (12)$$

According to the Mean Value Theorem for Integrals [23], there exists a value $c \in [v_{\min}, v_{\max}]$ such that

$$\psi(c) = \frac{1}{(v_{\max} - v_{\min})}\int_{v_{\min}}^{v_{\max}}\psi_A(v)dv \quad (13)$$

Therefore,

$$\mathbf{E}[AER_A] = \frac{2\lambda}{\pi}\psi(c) \quad (14)$$

There are two implications derived from the above analysis. Firstly, the values of r, k, and ω in Eq. (4) are calculated based on relative movement between node A and node B. Therefore, the AER reflects the *relative* mobility of a node with respect to its neighbours.

Secondly, if the lifetime of the encounter B defined in Eq. (1) is smaller than $T, \Delta t \le T$, node B will no longer be detected as a new encounter in the next detection.

It means that if a specific node and its neighbours move on the same direction and at same speed in duration $t > T$, there are no neighbours to be detected as new encounters, which results in AER = 0 at that node.

Lemma 1. *At a given density λ, if the AER value of node A equal to zero, node A is considered as relatively stationary to all nodes within its communication range and vice versa.*

Proof. Lemma 1 is proofed by contradiction as follows.

Assuming that node A is not relatively stationary with its neighbours while its AER value is still zero. Apparently, when node A relatively moves from a given place to another, the movement of node A yields a number of new encounters $N_E\,(A)$ with a probability $P(r)$. In other words, $\mathbf{E}\,[N_E\,(A)]$ in Eq. (3) is not equal to zero. This induces AER defined in Eq. (4) to be different from zero because $\mathbf{E}\,[N_E\,(A)]$ is nonzero. This contradicts the assumption above. The Lemma 1 has been proven.

Clearly, if the AER values are shared among nodes in the network (see Fig. 2); a node will be able to extend the radius of its prediction to detect whether the network is relatively static or mobile.

2.3. MSI and Analysis

Theorem 1. *If a node maintains a list of AER values of all nodes up to its k-hop neighbours, it can predict the network state, i.e., relatively static or mobile, within a radius of k+1 hop neighbours based on the Mobility State Indicator (MSI) as follows*

$$MSI = \sum_{i=1}^{n} AER_i = \begin{cases} 0\,, & \text{k + 1 hop neighbours are relatively stationary} \\ otherwise, & \text{k + 1 hop neighbours are mobile} \end{cases}$$

where n is the number of neighbours up to k-hop and a node itself; k≠0.

Proof. Theorem 1 is proven by an induction as follows.

(i) $k = 1$

Without loss of generality, let us examine the scenario illustrated in Fig. 2 in which a given node *A* has 4 neighbours, i.e., B, C, D, and E ($n = 5$). We have

$$MSI = \sum_{i=1}^{n} AER_i = AER_A + AER_B + AER_C + AER_D + AER_E \cdot$$

$MSI = 0$ iff $AER_A = AER_B = AER_C = AER_D = AER_E$.

Or

$$MSI = 0 \Leftrightarrow \begin{cases} AER_A = 0 \\ AER_{1-hop(A)} = 0 \end{cases}.$$

where $AER_{1\text{-}hop(A)}$ is the AER values of 1-hop neighbours of node *A*. Applying Lemma 1 to node *A* and its 1-hop neighbours, i.e., node *B*, *C*, *D*, and *E*, we have

$AER_A = 0 \Leftrightarrow$ node *A* is stationary w.r.t node *B*, *C*, *D*, *E*.

$AER_B = 0 \Leftrightarrow$ node B is stationary w.r.t node *A* and its 1-hop neighbours.

$\Leftrightarrow$ node *A* is stationary w.r.t node *B* and node B's 1-hop neighbours.

Similarly, node *A* is considered as stationary w.r.t node *C*, node *D* and node *E* and their 1-hop neighbours. In other words, node *A* is stationary w.r.t its 1-hop neighbours and 2-hop neighbours.

(ii) $k = 2$

$$MSI = 0 \Leftrightarrow \begin{cases} AER_A = 0 \\ AER_{1-hop(A)} = 0 \\ AER_{2-hop(A)} = 0 \end{cases} \cdot$$

By applying Lemma 1 to node *A*, 1-hop neighbours of node *A* and 2-hop neighbours of node *A*, node *A* is considered as stationary w.r.t its 3-hop neighbours.

(iii) $k = m$

$$MSI = 0 \Leftrightarrow \begin{cases} AER_A = 0 \\ AER_{1-hop(A)} = 0 \\ \quad\vdots \\ AER_{m-hop(A)} = 0 \end{cases} \cdot$$

Applying Lemma 1 to node *A*, to 1-hop neighbours of node *A*, and up to *m*-hop neighbours of node *A*, node *A* is considered as stationary w.r.t its *m*+1 hop neighbours. Theorem 1 has been proven.

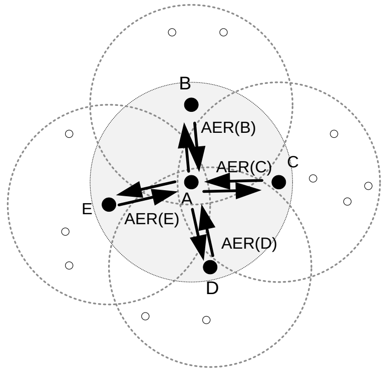

Fig. 2. AERs sharing

Corollary 1. *If k-hop neighbours of a node include all nodes in the network along with their AERs, the MSI can reflect the entire relative mobility of the network.*

The Corollary 1 can be derived from Theorem 1 by extending the *k*-hop neighbour so that *k*-hop neighbours cover all nodes in the network.

As the basic nature of *proactive routing*, routing information is shared to all nodes across the network. Therefore, it is readily to share AER and construct MSI by applying Corollary 1 for detecting network mobility state at each node. The detection rule (see Rule 1) is straightforwardly designed as follows.

Rule 1: Mobility State Detection Rule (for proactive routing)
If $MSI = 0$, nodes are relatively stationary.
If $MSI \neq 0$, nodes are mobile.

Note that each node *only* calculates MSI for the alive neighbours which appear as entries in the routing table. Therefore, out of energy or link breakage do not affect to the calculation of MSI.

2.4. GMSI and Analysis

For *reactive routing*, it is impossible to sum AERs of all nodes in the network based on the routing table because a reactive routing protocol does not have a mechanism to update network topology periodically as proactive routing protocols do. To this end, this paper proposes a method to obtain the global mobility state of reactive routing.

First of all, each node calculates the Local MSI which is a summation of 1-hop AERs.

$$Local\ MSI = \sum_{k=1}^{N} AER_k\ , \qquad (15)$$

where *N* is the number of 1-hop neighbours.

The Local MSI is then converted into Boolean value

$$msi = \begin{cases} 0 & \text{if } Local\ MSI = 0 \\ 1 & \text{if } Local\ MSI \neq 0 \end{cases}. \quad (16)$$

After that, each node calculates its GMSI by

$$GMSI = msi \vee GMSI_i^{(1)}, \quad (17)$$

where $GMSI_i^{(1)}$ are the GMSI of 1-hop neighbours; the notation $\vee$ denotes the Boolean union operation.

By doing so, GMSI can be shared across the network as illustrated in Fig. 3. Thus, the global mobility state can be detected by applying Rule 2.

Rule 2: Mobility State Detection Rule (for reactive routing)
If $GMSI = msi \vee GMSI_i^{(1)} = 0$, nodes are relatively stationary.
If $GMSI = msi \vee GMSI_i^{(1)} = 1$, nodes are mobile.

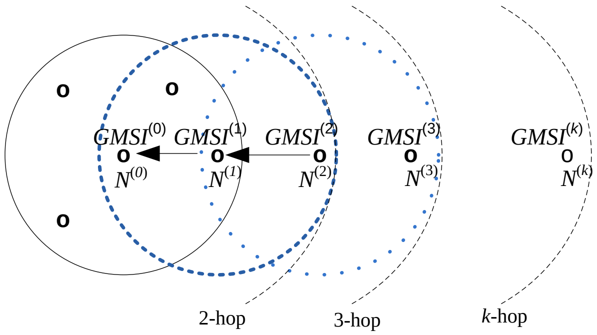

Fig. 3. Sharing GMSI among *k*-hop neighbours

Proof. Rule 2 is proven by deduction method as follows.

Without loss of generality, let a given node be the root node named as $N^{(0)}$, the other nodes are 1-hop, 2-hop, …, k-hop neighbours of $N^{(0)}$ as illustrated in Fig. 3. Their corresponding *msi* and GMSI are: $msi^{(0)}$/ $GMSI^{(0)}$, $msi^{(1)}$/ $GMSI^{(1)}$, $msi^{(2)}$/ $GMSI^{(2)}$, $msi^{(k)}$/ $GMSI^{(k)}$, where k is the distance measured by the number of hops from the given node to the farthest nodes in the network, $k = 1, 2, 3, \ldots$. Because node(s) $N^{(2)}$ are 1-hop neighbours of node $N^{(1)}$, hence, the Eq. (17) can be re-written as

$$GMSI^{(0)} = msi^{(0)} \vee GMSI_i^{(1)} = msi^{(0)} \vee [msi_i^{(1)} \vee GMSI_j^{(2)}];$$

Similarly,

$$GMSI_j^{(2)} = msi_j^{(2)} \vee GMSI_k^{(3)};$$

$$\ldots\ldots$$

$$GMSI_l^{(k)} = msi_l^{(k)}.$$

Therefore, the GMSI of $N^{(0)}$ can be calculated by

$$GMSI^{(0)} = [msi^{(0)} \vee msi_i^{(1)} \vee msi_j^{(2)} \ldots \vee msi_h^{(k)}]. \quad (18)$$

Note that $N^{(0)}$ might have many neighbours, this node will update its GMSI by applying Eq. (17) whenever it receives a neighbour's GMSI. This process allows nodes to update any changes of network mobility (represented by neighbour's GMSI) on its GMSI.

From Eq. (18), GMSI of a node is equal to zero only if *msi* of all other nodes are zero. In other words, if all nodes in the network are relatively stationary, GMSI of nodes is equal to zero and vice versa. Rule 2 has been proven.

3. Metric Self-Adaptive Routing (MSAR) Model

3.1. Routing Metric Discussion

This adaptive routing model applies two routing metrics for two mobility states of the network, i.e., static and mobile. In *static* conditions, ETX metric [2] is applied for routing to avoid the link interference among nodes. In *mobile* condition, PER metric [8] is employed to find a stable path for routing. This selection also helps to reduce time complexity at each node compared to MF metric [8] while still ensuring to find a stable path to forward data.

3.2. MSAR Algorithm

Proactive Routing

The adaptive algorithm designed based on Rule 1 for proactive routing has been previously demonstrated on Optimized Link State Routing (OLSR) [24] with two metrics, i.e., ETX and Mobility Factor (MF) [7] for static and mobile conditions respectively. Routing performance was observed improved in both static and mobile conditions [24].

This section, therefore, focuses on the adaptation of routing metric for reactive routing based on Rule 2, which is more complicated than proactive routing.

More importantly, Rule 2 can also be applied for proactive routing. This is because the proactive routing protocol also uses HELLO messages to build 1-hop neighbour table (e.g., OLSR [16]), therefore it allows proactive routing protocols to construct GMSI defined in Eq. (17). In other words, Rule 2 is more generic than Rule 1 since it can be applied for both proactive and reactive routing.

Reactive Routing

Based on Rule 2, each node can control its metric with respect to the network mobility state. In brief, nodes switch to ETX metric if the network mobility state is detected as static. Otherwise, nodes employ PER metric as their default setting (see Algorithm 1 – Check GMSI).

In reality, nodes could be "flickering" in terms of routing metric due to the quick changes of the network states between static and mobile, nodes should wait for certain duration τ (e.g., τ = 15s) to make sure the network truly static before switching to another metric to avoid "flickering" (Algorithm 1 – Check GMSI).

It should be set $\tau = m \times T$ where $m = 1, 2, 3 \ldots$ and T is the duration for checking GMSI so that nodes update the latest mobility state of the network via GMSI.

Algorithm 1: MSAR Algorithm for reactive routing

```
Initial metric → PER;
    /***--------------------- Check GMSI -----------------------****/
check GMSI periodically
|    if (GMSI = 0 in τ seconds) then
|    |    set "Metric Sync" flag ON and broadcast to neighbours;
|    |    if (metric is not ETX) then
|    |    |        metric → ETX;
|    |    end if
|    else
|    |    if (metric is not PER) then
|    |    |        metric → PER;
|    |    end if
|    end if
end check
    /***-------------------- Process HELLO --------------------***/
     Local MSI = sum AERs of 1-hop neighbours;     // Eq. (15)
     MSI → msi;                                    // Eq. (16)
     GMSI = msi ∨ (Get HELLO.[GMSI]);              // Eq. (17)

if ( "Metric Sync" flag received from a neighbour is ON) then
|    if (metric is not ETX) then
|    |        metric → ETX;
|    end if
else
|    if (metric is not PER) then
|    |        metric → PER;
|    end if
end if
    /***-------------------- Process RREQ ---------------------***/
     ETX (RREQ) = Get ETX recorded in RREQ message.
     PER (RREQ) = Get PER recorded in RREQ message.
switch (metric)
|    case "ETX":
|    |    if (ETX (RREQ) < ETX in Routing Table ) then
|    |    |    Update the backward route[1] with lower ETX;
|    |    end if
|    case "PER":
|         if (PER (RREQ) < PER in Routing Table) then
|         |    Update the backward route with lower PER;
|         end if
end switch
    /***--------------------- Process RREP ----------------------***/
     ETX (RREP) = Get ETX recorded in RREP message.
     PER (RREP) = Get PER recorded in RREP message.
switch (metric)
|    case "ETX":
|    |    if (ETX (RREP) < ETX in Routing Table ) then
|    |    |    Update the forward route[2] with lower ETX path;
|    |    end if
|    case "PER":
|         if (PER (RREP) < PER in Routing Table) then
|         |    Update the forward route with lower PER path;
|         end if
end switch
```

[1] the route is back to the source;
[2] the route forwards to the destination.

Metric Synchronization

To guarantee every node in the network switching to a particular metric at the same time when the condition described in Rule 2 holds, all nodes need to be informed for switching. This process, known as metric synchronization, is to ensure the *consistency* in terms of routing metric throughout the network.

In most routing protocols (e.g., AODV, OLSR) HELLO message is available and ready to use for performing this task (Algorithm 1 – Process HELLO) by adding a field name "Metric Sync" on it.

Updating Fresher Routes

Nodes in reactive routing need to update the fresher route whenever they receive a Route Request (RREQ) or a Route Reply (RREP) message. Note that a node updates the fresher backward route (if any) when it receives a RREQ message and updates the fresher forward route (if any) when it receives a RREP message (Algorithm 1 – Process RREQ and RREP). This ensures the current route recorded in the routing table having the lowest ETX or PER in backward and forward directions.

3.3. Route Selection Procedure

In principle, any routing machine will choose the best route which has the lowest cost to forward data. The cost of a path is determined based on the applied metric, e.g. HOP metric [25] costs a route by the number of hops that packets traverse along the path. Hence, the lowest cost path is actually the shortest path. In the proposed model, the metric changes according to network mobility state hence the criteria to cost a path changes correspondingly. That is, in static condition, nodes employ ETX metric for routing, which is calculated at each node by [2]

$$ETX = \frac{1}{d_f \times d_r} \quad (19)$$

where d_f is the forward delivery ratio which represents the probability of successful packets arrived at receiver; d_r is the reverse delivery ratio which represents the probability of successful ACK packets received; ETX ≥ 1. Based on Eq.(19), the source node should select the lowest ETX path (denoted P_{selected}) for routing among all available paths P_{j} from the source to the destination.

$$P_{selected} = \arg\min_{P_j} \left(\sum_{i=1}^{m} ETX\right), \quad (20)$$

where m is the number of links along the routing path; P_{j} is the set of available paths connecting the source and the destination.

This procedure offers a highest through path for nodes to route packets across the network. Readers can refer to work in [2] for more details.

In mobile condition, nodes employ Path Encounter Rate (PER), a new path routing metric which has been proposed in our previous work, for routing (see [8] for more details). The PER of a path is defined as a sum of squared Average Encounter Rates (AER) (see Eq. (21)) of all nodes along to the path.

$$PER = \sum_{i=1}^{m} AER_i^2 \quad (21)$$

where m is the number of nodes along the routing path.

Because AER reflects the relative mobility of a node compared to others around, the path which has the lowest PER is the most stable path. By doing so, packet will be routed over the most stable path in a high dynamic network caused by node movement to reduce link breakage rate thus reducing the number of lost packets [8]. Hence, the routing path is chosen by

$$P_{selected} = \arg\min_{P_j} (PER) \quad (22)$$

where P_j is the set of available paths connecting the source and the destination.

3.4. Control Packets and Routing Table

To apply ETX and PER metrics, control packets, i.e. Route Request (RREQ), Route Reply (RREP), HELLO, are extended by 2 bytes for ETX and 2 bytes for PER as illustrated in Fig. 4.

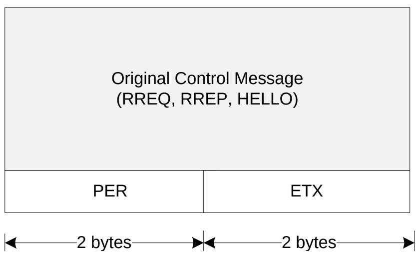

Fig. 4. Control message modification

Also, the routing table of each node is extended by two corresponding fields to record values of ETX and PER so that each node is able to calculate the cost of available paths.

3.5. Metric Time Complexity

Let n be the number of elements in neighbour sets of a node at time t_i. The time complexity for computing ETX metric of n neighbours is $O(n)$ because the algorithm needs to loop the neighbour list n times from the first to the final element to calculate the ETX of each one [26].

For computing AER metric, each node has to seek n elements in its current neighbour list to determine whether a node is a new encounter or not when it receives a HELLO message from a neighbour. If the sender of HELLO message is not in the list, the sender is marked as a new encounter; therefore, the time complexity for computing AER metric is also $O(n)$.

The AER value is then squared to construct the PER. In terms of time complexity, the square operation is implemented by bit-shifting technique resulting in time complexity of O (1). Thus, the total time complexity for calculating PER is $O(n)$.

4. Performance Evaluation

The proposed model MSAR was deployed on the original AODV protocol [13]. This deployment forms an adaptive routing protocol named as AODV-MSAR. The adaptation to network mobility states of AODV-MSAR was examined by changing among three mobility models (see Fig. 5 and TABLE 1). This is to produce the changes of the network state from absolutely static to relatively static and then to mobile.

To deploy AODV-MSAR, the HELLO message of the original AODV was extended to perform additional tasks: (1) detecting new encounters; (2) sharing the AER and GMSI to neighbours; (3) and synchronising metric.

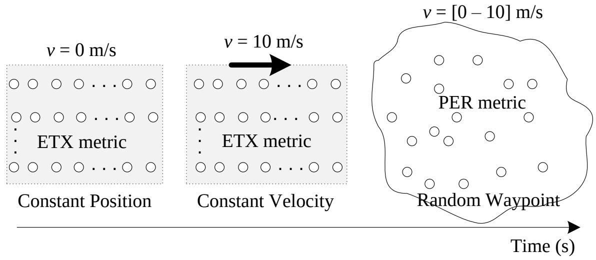

Fig. 5. Changing among three mobility models

Simulation Setup

The simulation was intentionally run in a high density scenario which is 100 nodes in an area of 500 × 1500 m^2 to induce interference and packet losses even in a static condition. This configuration is to express the role of the ETX metric in static conditions when the interference or packet losses appear mong nodes [2]. Node energy and traffic load were setup with sufficient amount such that the network never suffered from energy limitation and traffic congestion. This setup allows us to properly investigate the adaptation of the proposed model according to the changes of network states without being affected by other factors (see Table 1).

As discussed in Section 2.2, in order to help nodes accurately detect new encounters and network states, the encounter lifetime is set to be equal to the observation time, i.e., $\Delta t = T = 5$ seconds. It means that whenever a node restarts the counter for the next encounter detection, all encounters which have been previously met will be marked as old encounters and out of the next observation.

To evaluate the proposed model, following metrics were employed

- *Packet delivery ratio*: is the ratio of the data packets delivered to the destinations over those generated by the CBR sources.
- *Route error drops*: is the number of packets dropped due to route error.
- *Routing overhead*: is the total number of control messages including RREQ, RREP and Route Error (RERR).

TABLE 1. SIMULATION SETUP

Simulator	*ns-3* version 3.17
Number of nodes	100
Area	500m x 1500m
Mobility models	(1) Constant Position [27] (2) Constant Velocity [27] (3) Random Waypoint, pause time (0 – 2)s [27], [28]
Maximum velocity	[0 – 10] m/s
Routing protocols	AODV-MSAR, AODV-HOP, AODV-ETX, AODV-PER
Transmission range	250m
Physical/MAC layer	IEEE 802.11b
Propagation model	Two-ray ground
Traffic	10 pairs at 64 Kbps, 512 bytes/packet, UDP
Bandwidth	2Mbps
Encounter lifetime Δt	5 seconds
GMSI check (T)	every 5 seconds
Node energy	600 Joules
Transmit power	18 dBm
HELLO interval	2 (default setting), 5 seconds
τ	15s

In the simulation, each scenario was run in 300 seconds and repeated 20 times with different seed numbers to ensure *ns-3* generating different random sets for each run. Nodes were warmed-up 60 seconds to reach the steady state before sending traffic [29]. All simulation results were taken the average in 95 % of the confident interval.

4.1. Adaptation to the Network Mobility State

Fig. 6 shows the adaptation to the network mobility state of 3 random picked-up nodes among 100 nodes. Other nodes had similar results but they were not shown due to the space limit of the paper.

From the 10th second to the 60th second, the network is *absolutely static* because nodes are stationary (v = 0 m/s as illustrated in Fig. 6a). Therefore, there is no new encounter appearing in the communication range of any nodes across the network. This induces AERs of all nodes to be equal to zero, hence Local MSI are observed as zero in Fig. 6b, c, and d right after the 10th second (the 3rd small bubbles). This circumstance causes GMSI = 0 at all nodes at 20th second based on Eqs. (15), (16), (17), thereby nodes recognize that the network is static (or nodes are stationary). This is an ideal condition to apply ETX metric to find a highest throughput path for routing (it should be referred to the work in [2] for further studying of ETX metric).

From the 60th second to the 100th second, nodes all move at the speed of 10 m/s on the same direction as shown in Fig. 5 and Fig. 6a. This generates a change of the network mobility state from absolutely static to *relatively static*, MSI values as shown in Fig. 6b, c, and d are also observed to remain zero. In such a condition, there is no new encounter appearing across the network because all nodes are stationary w.r.t others. Thus, nodes have sufficient time to compute forward/backward packet delivery ratios to form ETX metric. It is a good condition to apply ETX for routing [2], [30].

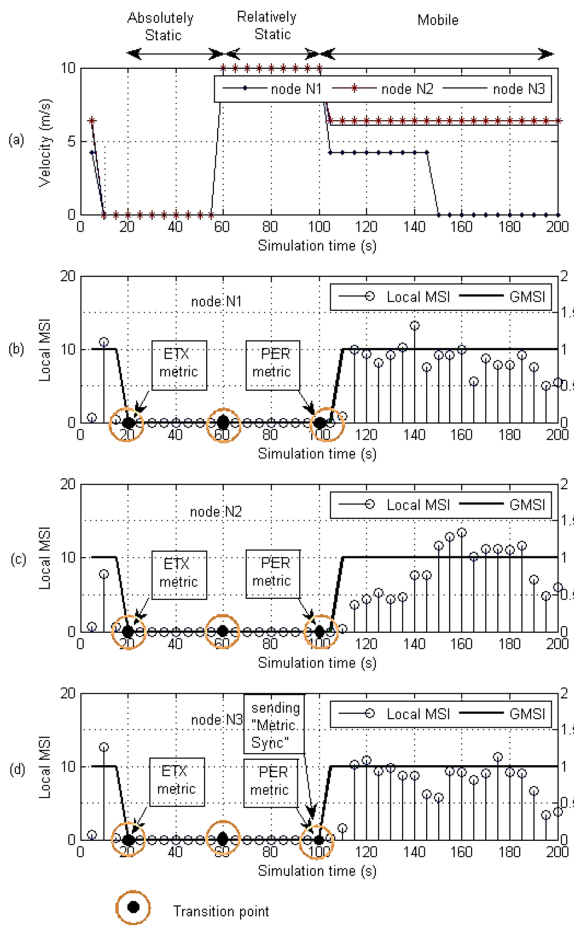

Fig. 6. MSI of three random picked-up nodes vs. Network states

After the 100th second, the network changes its state to *mobile*, nodes move randomly within the network area causing the appearance of new encounters at somewhere. This induces AERs at some nodes (or possibly all nodes) become non-zero and therefore their corresponding Local MSIs (as defined in Eq. (15)) are non-zero as well. Note that in mobile condition, nodes' speeds sometimes reach zero due to the nature of Random Waypoint mobility model as seen in Fig. 6a, however, AERs are more likely to be non-zero because nodes relatively move.

When GMSI(s) ≠ 0 at one or more nodes, the network is recognised as mobile according to Rule 2.

Though GMSI(s) ≠ 0 when the network changes its state from static to mobile (after the 100th second), nodes periodically check their GMSIs in different point in time; thus, they recognise the changes of GMSI values at different timeslots. As shown in Fig. 6c, node $N3$ is the node that first detects GMSI ≠ 0 among three nodes;

therefore, $N3$ is the node which first switches metric to PER. This leads to the fact that routing metrics will be inconsistent across the network if nodes are not synchronised when switching metric. In this case, node $N3$ under the control of Algorithm 1 broadcasts "Metric Sync" to force metric switching to PER at all other nodes as shown in Fig. 6d.

Whenever all nodes in the network change their routing metrics from ETX to PER, routing of AODV-MSAR is the same as routing under PER-based models. This paper does not investigate routing under PER, readers might refer to [8] for further investigations.

4.2. Impact of duration *T* for GMSI observation

Though the observation time T is independent from computing AER values as discussed in Section 2.2, it impacts on the reaction time of the proposed system when the network changes its state. Fig. 7 reveals that the shorter the observation period T is, the quicker the system adapts to the environment change.

As mentioned above, nodes use HELLO messages for detecting new encounters. If the observation time T is shorter than the HELLO interval (T_{HELLO}), the number of new encounters will not be updated before computing Local MSI. Therefore, it should be chosen $T \geq T_{HELLO}$. However, if the observation time is too large, the system will slowly adapt to the MANET's change.

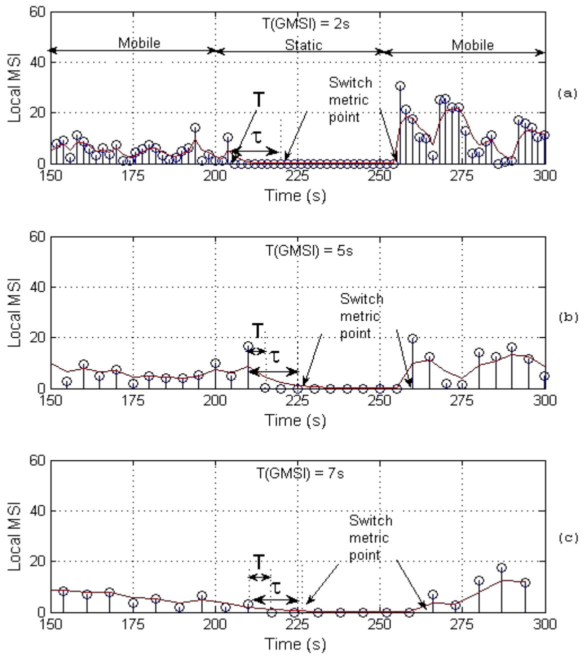

Fig. 7. Impact of the observation time T on the adaptability

4.3. Impact of a low mobility condition

It is also observed in Fig. 8 that ETX still offers a better packet delivery ratio than PER in a very low mobility condition, i.e., 1- 2 m/s. It turns out that in such a condition nodes still have sufficient times to calculate forward/reverse packet delivery ratios to construct ETX.

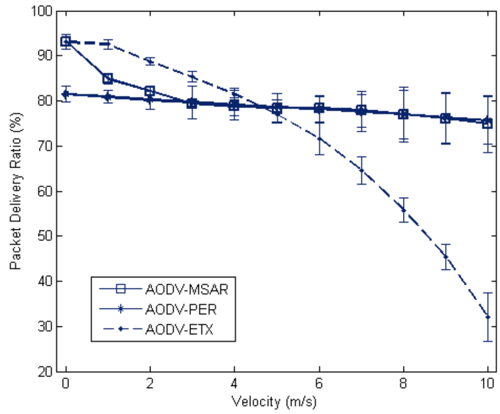

Fig. 8. Packet delivery ratio vs. Velocity without considering low mobility

It is acknowledged that the higher the AER value is, the more mobility the node is. Thus, it is possible to rely on AER to classify relative mobility of a node w.r.t other nodes in the vicinity into low, medium and high levels [31] and enable us to adjust network state from "strictly" static to "loosely" static. In particular, if the network is in very low mobility (i.e., 1 – 2 m/s), it is also considered as static. In such circumstances, nodes still employ ETX metric for routing to achieve a higher packet delivery ratio than that of PER metric.

To do so, Local MSI and *msi* as defined in Eq. (15) and Eq. (16) are re-defined as

$$\overline{local\ MSI} = \frac{1}{N}\sum_{i=1}^{N} AER_i\ , \qquad (23)$$

where N is the number of 1-hop neighbours.

$$msi = \begin{cases} 0 & \text{if } \overline{Local\ MSI} \leq \varepsilon \\ 1 & \text{if } \overline{Local\ MSI} > \varepsilon \end{cases} \qquad (24)$$

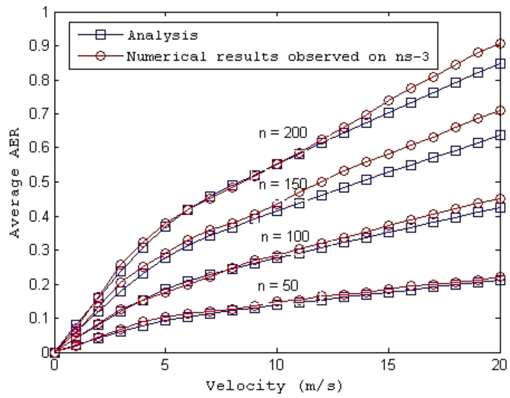

Fig. 9. AER at different velocities and densities

As shown in Fig. 9, if the AER ≤ 0.1, the mobility of nodes are very low (0 – 2 m/s) for all densities.

Therefore, ε is set to be 0.1 as the default value.

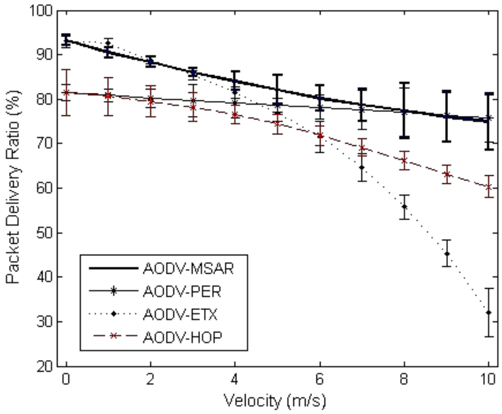

Fig. 10. Packet delivery ratio vs. Velocity with considering low mobility

By doing so, MSAR improves packet delivery ratio in very low mobility condition and produces a smooth transition between static and mobile conditions at the low mobility condition (i.e., 1 – 2 m/s). Fig. 10 shows an improvement of the proposed model when considering low mobility condition by using threshold ε. Particularly, the proposed system recognises the changes of network mobility state metrics if Local MSI $\leq \varepsilon$ instead of 0 (see Eqs. 23, 24). All other analysis and comparisons presented in Section 4.1 and 4.2, i.e. the adaptation ability, the impact of the duration T on routing performance, are still valid for it. The only thing difference between (with low mobility considering) Fig. 10 and Fig. 8 (without low mobility considering) is the improvement of packet delivery ratio (~ 10%) at low mobility condition (0-2 m/s).

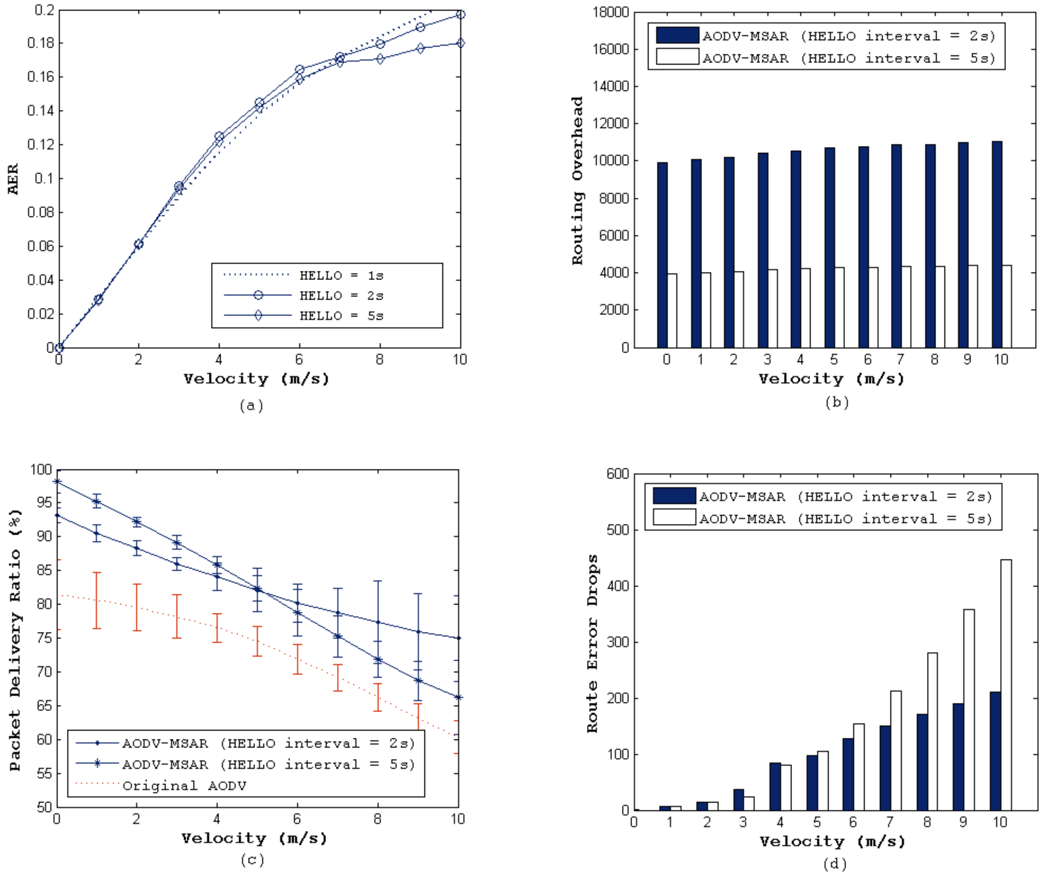

Fig. 11. Comparison of AODV-MSAR routing performance at two different HELLO intervals, i.e., 2 and 5 seconds: (a) Accuracy of AER; (b) Routing overhead; (c) Packet delivery ratio; (c) Route error drops.

4.4. Impact of HELLO frequency

The proposed model uses HELLO messages to detect new encounters appearing in the communication range to compute the AER value. Therefore, the period of sending HELLO messages remarkably effects to the accuracy of the AER, especially in mobility scenarios.

In most existing routing protocols, the period of broadcasting HELLO messages is fixed (e.g. the AODV sets this interval of every second). Therefore, if network mobility is high, the fixed HELLO frequency does not quickly enough track the appearance of a new encounter. This leads to an inaccurate AER value. As Fig. 11a shows, nodes detect AER imprecisely when the mobility increases above 6 m/s. In contrast, if node mobility is low (i.e., 0 to 5 m/s), the accuracy of AER is almost the same for both HELLO intervals, i.e., 2 and 5 seconds. This implies that a lot of HELLO messages become redundant if the network is static or low mobility.

Fig. 11b shows that the network can reduce nearly two-third of routing overhead in static condition if the HELLO interval is adjusted to 5 and 2 seconds instead of 1 second as default setting of the AODV-MSAR. This adjustment helps to increase 5.18 % of the packet delivery ratio compared to the basic AODV-MSAR at v = 0 m/s (see Fig. 11c). However, when the network mobility increases, the number of dropped packets grows very fast if the HELLO frequency is low as shown in Fig. 11d. This stems from the fact that the routing path based on PER metric is not the most stable caused by inaccurate AER values when the mobility increases. This induces a rapid reduction of packet delivery ratio of AODV-MSAR with HELLO interval of 5 seconds when network mobility increases (see Fig. 11c).

One of solutions for this issue is to dynamically adjust the HELLO frequency according to node mobility as proposed in [19], [20] to diminish redundant HELLO messages while still detecting new encounters properly. This paper, however, focuses on the adaptation of routing metrics based on the network mobility states, the adaptation of the HELLO frequency is out of the scope of this research.

4.5. Routing Latency and Overhead

This paper focuses on the adaptation of the proposed model to the change of mobility state of MANET. Once the metric changes to specific one (i.e. ETX or PER), routing performance of the proposed model will exactly be the same as that of ETX or PER correspondingly. Thus, latency and overhead of the proposed system are radically investigated in [2] and [8]. In principle, HOP metric offers the shortest path for routing, hence the end-to-end delay produced by HOP metric is shortest compared to all others. In other words, routing paths under ETX and PER are longer than that of HOP metric, however they offer the highest throughput path [2] and the most stable path [3] for routing under static and mobile conditions respectively. In static condition, routing overhead under ETX and HOP is the same because there is no route breakage, nodes do not need to broadcast control packets to re-discover a new route [2]. In mobile condition, routing overhead under PER metric is less than that of HOP metric because the routing path is the most stable, therefore the number of route breakages reduces compared the shortest path (under HOP metric) [3], thus decreasing the number of control packets (or routing overheads).

In this paper, we did not do those investigations to avoid a repetition of work done in [2] and [8].

4.6. Comparison to other adaptive routing schemes

An adaptive routing protocol is the protocol that can change its behaviour (e.g., parameters, forwarding policies, routing modes) corresponding to the changes of network environment. Depending on the objective(s) of adaptation, adaptive routing protocols should monitor different parameters of the network [32] to accordingly change their behaviours as described in Table 2.

TABLE 2. ADAPTIVE ROUTING SCHEMES COMPARISON

#	Protocol	Adaptation objective	Monitoring parameter	Behaviour changed
1	AH [20]	Traffic demand	Number of sending packets in buffer	Adjusting Hello freq.
2	CRP [21]	Traffic Congestion	Buffer size	Splitting traffic to "bypass route"
3	AROD [10]	Topology change (due to density and mobility)	Routing table changes	Changing message priority
4	ARSMA [11]	Topology change (link break rate)	Route broken rate	Switching to backup route
5	ACRP [12]	Topology change (due to mobility and application type)	Link break rate; Interface queue length; Application type	Routing strategy (Proactive /Reactive)
6	MAHR [15]	Topology change (due to mobility changes)	Mobility Ratio (MR) based on link duration	Routing strategy (Proactive /Reactive)
7	CAHR [17]	Zone topology change (due to mobility)	Zone's key nodes	Changing to another key node
8	TAP [19]	Topology change (due to mobility)	Number of new neighbours	Adjusting Hello freq.
9	MSAR(*)	Topology change (due to mobility and density)	Global mobility state indicator (GMSI)	Changing metric (ETX and PER)

(*) Our proposed model

It can be clearly seen that there are many strategies to adapt to the changes of network topology as shown in TABLE 2. Adjusting HELLO frequency as proposed in [19] mainly helps to save energy consumption at each node. However, it might impact to the accuracy in detecting a new neighbour appeared. Meanwhile, switching between two routing modes (proactive /reactive) as proposed in [12], [15] enables MANETs to improve routing performance (packet delivery ratio, routing overheads, end-to-end delay). However, this strategy faces to a challenge of synchronisation when switching between two routing modes.

To the best of our knowledge, the proposed MSAR is the first model to adapt to the topology change by switching between two routing metrics. In terms of implementation, MSAR is considered as much simpler than those routing models proposed in [12], [15] (i.e., switching between two routing modes) but it still helps to improve routing performance in different mobility and density conditions. This is because MSAR operates based on one routing mode with unique routing table rather than two routing modes and two routing tables as those in [12] and [15] do.

5. Conclusion and Future Works

This paper has introduced a distributed routing model that can help each node adapt routing metrics to the mobility states of the network. The proposed model allows nodes to detect whether the network is relatively static or mobile based on an indicator named MSI (for proactive routing) or GMSI (for reactive routing) without the support of the GPS. Having said that GMSI is designed for reactive routing, it is more generic than MSI and can also be applied for proactive routing. The mobility detection model proposed in this paper could be considered to apply for many other models in order to improve routing performance of MANET (e.g., adjusting HELLO frequency to save energy at each node or clustering an ad hoc network into static or mobile group of nodes).

Based on MSI/GMSI, an adaptive routing scheme named MSAR has been proposed to employ ETX and PER metric for each detected state (i.e., static or mobile) to achieve the optimum routing performance. This is a remarkable improvement compared to the pure ETX-based and PER-based routing models which outperform HOP metric only for a specific working condition, i.e., static or mobile.

For the future works, we will investigate and evaluate the proposed scheme in a heterogeneous ad hoc network with different mobility models.

ACKNOWLEDMENT

One of the authors, Tran The Son would like to thank for the financial support from Vietnamese Gov. under the Project no. 165 – Decision no. 202/QD-BTCTW to carry out this project.

REFERENCES

[1] A. Boukerche, B. Turgut, N. Aydin, M. Z. Ahmad, L. Bölöni and D. Turgut, “Routing protocols in ad hoc networks: A survey,” *Computer Networks,* vol. 55, no. 13, pp. 3032-3080, 2011.

[2] D. S. J. De Couto, D. Aguayo, J. Bicket, and R. Morris, “A High-Throughput Path Metric for Multi-Hop Wireless Routing,” in *ACM Proc. of the 9th Annual Int'l Conf. on Mobile computing and Networking,* New York, NY, USA, 2003.

[3] R. Draves, J. Padhye, and B. Zill, “Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks,” in *Proc. ACM MobiCom ‘04,* Sept 2004.

[4] W. Su, S. J. Lee, and M. Gerla, “Mobility Prediction and Routing in Ad Hoc Wireless Networks,” *Int'l Journal of Network management,* vol. 11, no. 1, pp. 3 - 30, 2001.

[5] J. Boleng, W. Navidi, and T. Camp, “Metrics to Enable Adaptive Protocols for Mobile Ad Hoc Networks,” in *Int'l Conf. on Wireless Networks (ICWN 02),* pp. 293 - 298, 2002.

[6] A. Khelil, P. J. Marron, and K. Rothermel, “Contact-based Mobility Metrics for Delay-Tolerant Ad Hoc Networking,” in *Proc. of the13th IEEE Int'l Symposium on Modelling, Analysis, and Simulation of Computer and Telecommunication Systems,* 2005.

[7] C. Wu, K. Kumekawa, and T. Kato, “A MANET protocol considering link stability and bandwidth efficiency,” in *Int'l Conf. on Ultra Modern Telecommunications & Workshops (ICUMT '09),* 2009.

[8] T. T. Son, H. Le-Minh, G. Sexton, and N. Aslam, “A novel encounter-based metric for mobile ad-hoc networks routing,” *Ad Hoc Networks,* vol. 14, pp. 2 -14, 2014.

[9] Q. Zhang and D. W. Matolak, “Ad Hoc Network Metrics: Which is Best?,” in *Global Communications Conference (GLOBECOM 2012),* CA, 2012.

[10] C. Liu and J. Wu, “Adaptive Routing in Dynamic Ad Hoc Networks,” in *IEEE Wireless Communications and Networking Conference (WCNC),* USA, pp. 2603 - 2608, 2008.

[11] Y. C. Lin and C. W. Ke, “Adaptive Route Selection in Mobile Ad Hoc Networks,” in *the 4th IEEE Int'l Conf. on Communications and Networking (ChinaCOM 2009),* 2009.

[12] C. Fathy, M. T. El-Hadidi and M. A. El-Nasr, “Fuzzy-based Adaptive Cross Layer Routing Protocol for Delay Sensitive Applications in MANET,” in *Int'l Conf. of Communications (ICC 2012),* Ottawa, ON, pp. 248 - 253, 2012.

[13] C. Perkins, E. Belding-Royer, and S. Das, “Ad-hoc On-demand Distance Vector Routing (AODV),” IETF RFC 3561, July 2003.

[14] C. Perkins and P.Bhagwat, “Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for mobile computers,” in *Conf. on Communications Architectures, Protocols and Applications (SIGCOMM '94),* Newyork, USA, 1994.

[15] D. W. Kum, W. K. Seo, J. I. Choi and Y. Z. Cho, “Mobility Adaptive Hybrid Routing for Mobile Ad hoc Networks,” in *the Int'l Conf. on Computer Sciences and Automation Engineering (CSAE),* pp. 377-381, 2012.

[16] T. Clausen, and P. Jacquet, “Optimized Link State Routing Protocol (OLSR),” IETF RFC 3626, Oct 2003.

[17] X. Jiaqi, X. Chunxiu, Z. Xijie and X. Xiao, “A centralized adaptive hybrid routing mechanism for Ad Hoc networks,” in *17th International Symposium on Wireless Personal Multimedia Communications (WPMC2014),* 2014.

[18] Z. J. Haas, “A routing protocol for the reconfigurable wireless networks,” in *Proc. of the 6th IEEE Int'l Conf. on Universal Personal Communications (ICUPC),* 1997.

[19] F. Ingelrest, N. Mitton, and D. Simplot-Ryl, “A Turnover based Adaptive HELLO Protocol for Mobile Ad Hoc and Sensor Networks,” in *Int'l Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS '07),* Istanbul, Turkey, 2007.

[20] S. Y. Han and D. Lee, “An Adaptive Hello Messaging Scheme for Neighbor Discovery in On-Demand MANET Routing Protocols,” *IEEE Communications Letters,* vol. 17, no. 5, pp. 1040 - 1043, 2013.

[21] D. A. Tran, H. Raghavendra, “Congestion Adaptive Routing in Mobile Ad Hoc Networks,” *IEEE Transactions on Parallel and Distributed Systems,* vol. 17, no. 11, pp. 1294 - 1305, 2006.

[22] S. Chettibi and S. Chikhi, “Dynamic fuzzy logic and reinforcement learning for adaptive energy efficient routing in

mobile ad-hoc networks," *Applied Soft Computing*, vol. 38, pp. 321 - 328, 2016.

[23] H. Jeffreys and B. S. Jeffreys, "Mean-Value Theorems," in *Methods of Mathematical Physics*, Cambridge University Press, 3rd ed., pp. 49 - 50, 1988.

[24] T. T. Son, H. Le-Minh, G. Sexton, and N. Aslam, "Self-adaptive proactive routing scheme for mobile ad-hoc networks," *IET Networks*, vol. 4, no. 2, pp. 128 - 136, 2015.

[25] D. E. Comer, Internetworking with TCP/IP - Vol. I: Principles, Protocols, and Architecture, Printice Hall, ISBN 0-13-018380-6, 4th edition, 2000.

[26] H. S. Wilf, "Algorithms and Complexity," 1994. [Online]. Available: http://www.cis.upenn.edu/wilf.

[27] "A Discrete-Event Network Simulator," ns-3, 2013. [Online]. Available: https://www.nsnam.org/doxygen-release/group__mobility.html.

[28] T. Camp, J. Boleng and V. Davies, "A Survey of Mobility Models for Ad Hoc Network Research," in *Wireless Communications & Mobile Computing (WCMC)*, September 2002.

[29] R. Y. Rubinstein, Simulation and the Monte Carlo method, John Wiley & Sons, ISBN 0-471-08917-6, 1981.

[30] R. Draves, J. Padhey, and B. Zill, "Comparison of Routing Metrics for Static Multi-hop Wireless Networks," in *SIGCOMM '04*, 2004.

[31] T.T. Son, H. Le-Minh, G. Sexton and N. Aslam, "Bayesian Model for Mobility Prediction to Support Routing in Mobile Ad-hoc Networks," in *the 24th IEEE PIMRC '13*, London, 2013.

[32] B. Paillassa, C. Yawut, and R. Dhaou, "Network awareness and dynamic routing: The ad hoc network case," *Computer Networks*, vol. 55, no. 9, pp. 2315 - 2328, 2011.