Context-aware Opportunistic Routing in Mobile Ad-hoc Networks Incorporating Node Mobility

Zhongliang Zhao*, Denis Rosário*,†, Torsten Braun*, Eduardo Cerqueira†
*Institute of Computer Science and Applied Mathematics, University of Bern, Switzerland
†Faculty of Computer Engineering and Telecommunication, Federal University of Para, Brazil
Email:zhao@iam.unibe.ch, denis@ufpa.br, braun@iam.unibe.ch, cerqueira@ufpa.br

***Abstract*—Opportunistic routing (OR) employs a list of candidates to improve reliability of wireless transmission. However, list-based OR features restrict the freedom of opportunism, since only the listed nodes can compete for packet forwarding. Additionally, the list is statically generated based on a single metric prior to data transmission, which is not appropriate for mobile ad-hoc networks. This paper provides a thorough performance evaluation of a new protocol - *Context-aware Opportunistic Routing (COR)*. The contributions of COR are threefold. First, it uses various types of context information simultaneously such as link quality, geographic progress, and residual energy of nodes to make routing decisions. Second, it allows all qualified nodes to participate in packet forwarding. Third, it exploits the relative mobility of nodes to further improve performance. Simulation results show that COR can provide efficient routing in mobile environments, and it outperforms existing solutions that solely rely on a single metric by nearly 20 - 40 %.**

***Index Terms*—Context Awareness, Opportunistic Routing, Mobility Incorporation, Mobile Ad-hoc Networks (MANETs).**

I. Introduction

Due to lossy nature, wireless networks have challenges to ensure good routing performance. The wireless channel is unreliable due to fading and interference, which makes it hard to route packets. Node mobility also incurs frequent topology changes, which causes significant overhead on recalculating paths. Routing in constantly changing networks needs to react to network dynamics to achieve efficient and reliable network usage. All sources of dynamics in these environments could be considered as context for route selection. Therefore, a routing solution that considers the network dynamics could be called context-aware routing.

Opportunistic routing (OR) is one promising technique to improve the performance of wireless ad-hoc networks. In OR, a source node does not pre-select a single specific node to send unicast packets. Instead it chooses a set of nodes (referred to as *candidates*) as potential forwarders, and broadcasts the packet. Multiple receivers of the packet coordinate with each other such that the one with the highest priority will forward the packet. In this way, OR postpones the selection of the forwarder to the receiver side, which increases reliability and robustness of multihop wireless communication.

The performance of OR depends on several factors. The first one is the selection of candidates. Although involving all neighbors with lower costs to the destination seems to be an effective solution, the overhead is expected to grow with an increasing number of candidates. Prioritizing the candidates is the second influential factor. In general, different metrics can be used to define the priority list, and the choice of metrics affects protocol performance. The third factor is the coordination among multiple receivers of a packet, to ensure that only one of them will forward the packet.

Candidate selection and prioritization in OR are similar to building routing tables in MANET routing. Numerous OR protocols have been proposed [1] [2] [3]. However, most of them statically select and prioritize candidates prior to packet transmission according to end-to-end route costs using single-path metrics, such as Expected Transmission Count (ETX). They assume that the ETX of a path is the sum of the ETX of each hop, and the candidate with the minimum end-to-end ETX is assigned with the highest priority. However, it is hard to get the ETX of a path under unknown dynamics.

When nodes become mobile, existing candidate list-based OR protocols can not work well, since the pre-calculated list will be no longer valid if the network topology changes. In this case, beaconless-based geographic routing, such as Beacon-Less Routing (BLR) [4], might be a better option due to its stateless feature. Moreover, if only position information is used, it is possible to miss some good forwarding candidates due to frequent topology changes. Therefore, relative movement of nodes should also be considered to further improve robustness of routing protocol. In general, as networks become dynamic, the awareness of nodes' diverse context information is of great importance to improve performance.

Context is any information that can be used to characterize the situation of an entity [5]. When referring to MANETs, context information can be grouped into three types: local context, link context, and global context. Local context includes various attributes of mobile nodes such as location, mobility (speed and direction), residual energy, storage and processing capability. Link context includes properties associated with wireless links such as link quality and available bandwidth. Global context includes diverse attributes of networks such as network topology, traffic information, and node encounter. Due to the dynamic nature of MANETs, it is expensive to obtain and maintain global context. Therefore, local and link context should be exploited efficiently to improve performance. Context-aware routing generally implies that the routing process is made based on multiple context criteria, which significantly influence routing performance.

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To address the above issues, we propose a new protocol - Context-aware Opportunistic Routing (COR). COR allows all qualified nodes to participate in packet forwarding. It jointly utilizes multiple contexts to select forwarders, based on multi-criteria decision theory [6]. Compared to previous OR protocols, COR has three features: it simultaneously exploits multiple types of context information such as link quality, geographic progress, and residual energy of nodes to make routing decisions; it has a new definition of progress, which makes the candidate selection process converge more rapidly and the collision probability is also reduced; it incorporates the relative movements of nodes to further improve performance. Extensive simulation results show that COR can provide efficient and robust routing in MANETs.

The structure of this paper is as follows. Section II outlines the problems of existing opportunistic routing protocols when nodes are mobile and the benefits of context-aware routing. Section III describes the proposed COR protocol. Simulations and analysis of results are presented in Section IV. Section V concludes the contributions of this work.

II. Related Work

OR differs from traditional routing in mainly two aspects: multiple relay candidates and distributed relay selection at the receiver side after data transmission. Therefore, candidate selection and coordination are two primary components of OR.

ExOR [1] selects candidates based on ETX. Zhong et al. proposed a new metric - Expected Anypath Transmission (EAX), and ranked the candidates accordingly [2]. Darehshoorzadeh et al. performed a study of candidate selection solutions, from which we can find out that existing OR protocols select and prioritize a list of candidates according to a single metric, such as ETX, EAX, etc [3].

Existing OR protocols choose the next hop based on a candidate list, which is created prior to data transmission. Additionally, they stipulate that only the listed nodes can compete for relaying, which prevents a non-listed node moving to a better position from becoming a more suitable candidate. Wang et al. stated that nodes that are not in the candidate list may also be useful, as far as they overhear the packet and have certain geographical progress towards the destination [7]. Therefore, current candidate list-based OR protocols can not provide the best reliability in mobile environments.

Different coordination mechanisms have been proposed, among which the distance-based timer approach is the most straightforward one, e.g. Dynamic Forwarding Delay (DFD) of BLR. In BLR, after receiving a packet from a source, candidates start a timer before forwarding it. The node closer to the destination has the shortest delay, and rebroadcasts first. Its neighboring nodes then cancel their timers when overhearing this rebroadcast. BLR defines a forwarding area, such that only the nodes within the area are qualified to compete for packet forwarding. This reduces the packet duplication.

Context-aware routing enables network nodes to use information collected from the environment or users to participate in packet forwarding. Several efforts have been made in context-aware routing. CAR [8] took nodes' connectivity and contact patterns as input to determine the best forwarding node. However, in CAR, nodes have to periodically measure and combine their attributes and disseminate them to neighbors, which is not appropriate for the dynamics of MANETs. Boldrini et al. designed a genetic context-aware middleware to infer potential mobility or contact patterns to help routing packets in opportunistic networks [9]. Therefore, in lossy mobile environments, the more information a routing protocol considers, the more accurate it can understand the network.

From the analysis of related work, we see that existing candidate list-based OR protocols have several drawbacks in mobile scenarios, and it is beneficial to consider multiple context information to make a joint routing decision in MANETs. In this paper, we design a new opportunistic routing protocol, which uses link quality, geographical location, energy, and mobility to disseminate packets in a fully distributed manner.

III. Design of Context-aware Opportunistic Routing

In this section, we present the design of COR - Context-aware Opportunistic Routing. COR utilizes various context information to make routing decisions. Forwarding candidates separately calculate a delay timer based on their local observations of the interested context.

A. Dynamic Forwarding Delay (DFD)

COR is based on BLR's geographical routing, which means it is assumed that each node is aware of its location via a GPS-like device. Whenever a source node wants to send a packet to a destination, it broadcasts the packet, including the location of itself and the destination. Due to the available GPS information, neighbors that successfully receive the packet can check whether they are closer to the destination or not. If yes, they will act as relaying candidates and start a local timer based on the idea of Dynamic Forwarding Delay (DFD). All possible candidates compute their DFD values, and the node that generates the shortest DFD becomes the relay and forwards the packet first. It stores its current position in the packet header, and the other candidates drop the packet when overhearing this relaying. The re-broadcasted packet is used as a passive acknowledgement to inform the packet sender about which node has been selected as the forwarder. After this, the sender is aware of its next hop, and it will transmit subsequent packets to the chosen forwarder using unicast to reduce the drawbacks introduced by broadcasting [4].

In COR, each node calculates its DFD based on multiple context information. In general, there is no limitation about the context chosen in COR. By analyzing factors affecting the performance, this paper chooses four types of context: *link quality*, *progress*, *residual energy*, and *link validation duration*. To reflect the importance of each context, we apply the so-called *Weights method* [6] to assign a weight to each context. The calculation of DFD is presented in Eq. (1):

$$\begin{aligned} \text{DFD} \quad = \quad & (\alpha \times \text{Link Quality} + \beta \times \text{Progress} \\ & + \gamma \times \text{Residual Energy} + \delta \times \text{LIVE}) \times DFD_{Max} \end{aligned} \tag{1}$$

Coefficients α, β, γ, and δ are the weights of each context and $\alpha+\beta+\gamma+\delta=1$. DFD_{Max} is the predefined maximum delay allowed at each node. Details of the explanation and calculation of each context are presented in below.

1) Link Quality: Radio irregularity is a non-negligible phenomenon in wireless communication. As shown in Figure 1, wireless radio transmission ranges are normally irregular and resulting Packet Delivery Ratio (PDR) distribution is non-uniform, which can significantly affect system performance [10]. However, most routing protocols do not consider this and they simply assume that the transmission range is a circle such that nodes within the radio range can always hear each other. COR uses the instantaneous link quality to calculate DFD. The calculation of the "Link Quality" as part of (1) is shown in Eq. (2), which has a value ranging from 0 to 1. The link quality is usually measured at the physical layer. For example on sensor nodes, the CC2420 radio chip measures the physical layer information and provides the Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI) for each received packet. These parameters directly reflect the instantaneous link quality. In our study, we use LQI as the indicator of link quality between two nodes.

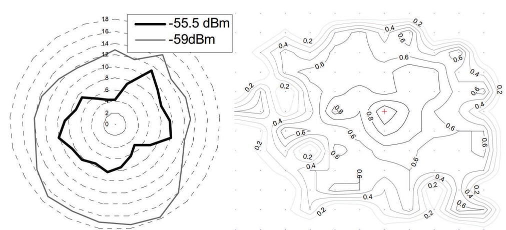

Fig. 1. Irregular radio range(left) and resultant PDR distribution(right)

Baccour et al. [11] used PDR to classify links into three categories: namely connected (PDR$>90\%$), transitional ($10\%<$ PDR$<90\%$), and disconnected (PDR$<10\%$). Based on this, we define the bounds of good links and bad links by two threshold values: LQI_{Good} and LQI_{Bad}, whose values are determined by experiments. We define LQI_t as the measured LQI value of a link and LQI_{Max} as the predefined maximum value of LQI_t. The candidate node must ensure that a minimum link quality is achieved to guarantee successful packet transmission. When a node receives a packet, it derives LQI_t for the incoming link (the link over which the packet is received). For example, a node with a good link ($LQI_t > LQI_{Good}$) will return 0 to "Link Quality", which means a node with a good link will produce zero delay to the DFD. A node with a bad link ($LQI_t < LQI_{Bad}$) will produce a large delay contribution to the DFD.

$$\text{Link Quality} = \begin{cases} 0 & \text{if } LQI_t > LQI_{Good} \\ \frac{LQI_{Max}-LQI_t}{LQI_{Max}} & \text{if } LQI_{Bad} < LQI_t < LQI_{Good} \\ 1 & \text{if } LQI_t < LQI_{Bad} \end{cases} \quad (2)$$

2) Progress: Eq. (3) defines how the "Progress" value in Eq. (1) is calculated. The node with larger geographical progress towards the destination generates a smaller value.

$$\text{Progress} = \begin{cases} \frac{2R-P_i}{2R} & \text{if } Dist_{R-D} > R \\ 0 & \text{if } Dist_{R-D} < R \end{cases} \quad (3)$$

P_i is the progress of node i, R is the radio range, and $Dist_{R-D}$ is the distance between the relay and the destination. We define the progress as the sum of two segments, as shown in Figure 2. Suppose that S is the source and D is the destination, A and B are two possible relay nodes for S within its transmission range. A' and B' are the intersection points of the circles that are centralized at the candidate nodes A & B and line S-D. In Figure 2, the progress of A (P_A) is composed of two parts: the projection of line S-A on line S-D (p_1), and the projection of line A-A' on line S-D (p_2). Therefore, P_A = p_1 + p_2 and P_B = p_3 + p_4. With this new definition, we reduce the possible collision that is caused by two nodes with the same projection progress. For example, A and B have the same projection progress on line S-D (p_1 = p_3). Because BLR uses projection progress, A and B generate the same delay and rebroadcast the packet at the same time, which leads to collisions. However, with the new definition, this can be avoided. Because even if p_1 = p_3, B is closer to line S-D, and it has a larger progress than A ($P_B = p_3+p_4 > P_A = p_1$ + p_2), so it rebroadcasts the packet before A and the collision is reduced. Besides, S can reach D with only one hop via B, which can not be achieved if A is chosen.

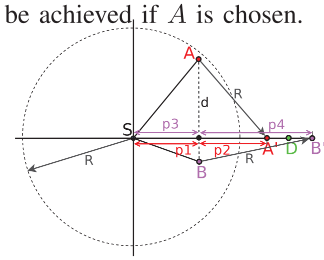

Fig. 2. Progress definition of forwarding candidates

3) Energy: Energy is another important issue in wireless mobile ad-hoc networks due to the fact that wireless nodes are usually battery-powered and energy resources are scarce. For example, in mobile wireless sensor networks, sensors have very limited energy resources and they spend most energy for movement and packet transmission. Thus, energy should also be considered to provide energy-efficient routing decisions. Eq. (4) defines the energy part of the DFD function. A node with high residual energy (E_r) generates a small "Residual Energy" value, which means a small contribution to the DFD.

$$\text{Residual Energy} = \begin{cases} \frac{E_0-E_r}{E_0} & \text{if } E_r > E_{Min} \\ 1 & \text{if } E_r < E_{Min} \end{cases} \quad (4)$$

E_0 and E_r are initial and residual energy of each node, respectively. In MANETs, a mobile node, e.g., an Unmanned Aerial Vehicle (UAV), can only be selected as forwarder if: (i) it has enough energy (E_{Min_1}) to transmit packets during the validity time of a link with a sender; and (ii) after the link validity time (defined in III-A4), the node still has enough energy (E_{Min_2}) to move to the control center. This means, in (4), E_{min} is composed of two parts: $E_{min}=E_{Min_1}+E_{Min_2}$.

4) Link Validity Estimation (LIVE): Geographic routing selects a forwarder solely based on node positions. However, in mobile scenarios (e.g., MANETs), if only node position information is used, it is possible to miss some good candidates due to frequent topology changes. Therefore, node mobility information (moving direction and speed) should also be considered to further improve performance.

COR exploits nodes' relative movement direction. It prefers a node moving to the destination, even if its current location is not favorable. As shown in Figure 3, A should take C as a relay, since C moves to D and it can opportunistically act as a data mule for A to bring the packet closer to D.

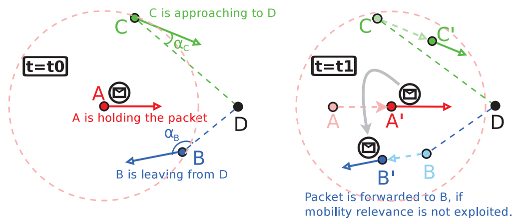

Fig. 3. An example of inefficient packet relays without mobility relevance

If a source wants to send a packet, it adds its location and mobility data (speed and direction) into the header and broadcasts it. After receiving a broadcast, if a node is qualified, it starts a link validity estimation process to derive the validity duration of that link. Eq. (5) defines how the "LIVE" part in Eq. (1) is calculated, where α is the angle between a node's moving direction and the line connecting the destination and itself (as shown in Figure 3). A node with α = 0 means it is moving towards the destination, therefore, it is preferred and generates a short delay in Eq. (1). Since α = 180 means a node moves into the opposite direction of the destination, it is not preferred. T_{LV} is how long the link will hold, and is calculated by Eq. (6). For example in Figure 4, if node A and B move with speed V_a, V_b and direction θ_a, θ_b, given their initial location of (X_A,Y_A) and (X_B,Y_B), they can compute the validity time of the link (T_{LV}) between them.

$$\text{LIVE} = \frac{1}{(\frac{180-\alpha}{180})^2 \times T_{LV}} \tag{5}$$

$$\begin{aligned}&[(X_B + V_b \cdot \cos\theta_b \cdot T_{LV}) - (X_A + V_a \cdot \cos\theta_a \cdot T_{LV})]^2\\&+[(Y_A + V_a \cdot \sin\theta_a \cdot T_{LV}) - (Y_B + V_b \cdot \sin\theta_b \cdot T_{LV})]^2 = R^2\end{aligned} \tag{6}$$

Moreover, the source node should also know this "LIVE" value such that it can send subsequent packets using unicast within "LIVE". When this link validity time expires, the source starts another broadcast. If any node of the link changes its mobility before T_{LV} expires, it has to inform this change to the other. We assume that a node is aware of the change of its movement (either speed or direction). As soon as a node changes its trajectory, it disseminates the new mobility data by piggybacking in the packet header, such that the other node of the link can update the validity time of that link timely.

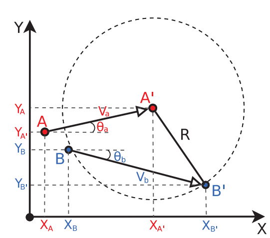

Fig. 4. Link validity estimation calculation process

B. Reducing Duplicates at the Destination

Beacon-less protocols, where next hops are selected in a fully distributed way, generate a tremendous amount of duplicates and degrade performance. To avoid that, the destination should notify its neighbors when it receives a packet by rebroadcasting a message including the sequence number of the received packet. Neighbors that still hold the packet check if the packet comes from the destination: if yes, they cancel the timer and delete the packet; if not, the timers continue to count down. For nodes that do not have that packet, the received broadcast packet is simply dropped, if it comes from the destination; otherwise, a timer will be triggered.

IV. Performance Evaluation

To evaluate the performance of COR, we perform extensive simulations in OMNeT++ using the extended version of our evaluation framework [12]. We compare COR against the well-known geographic routing protocol GPSR and beaconless routing protocol BLR with varying node densities, movement pause intervals, and speeds. PDR, goodput, and average end-to-end delay are measured to compare protocol performance.

A. Simulation Settings

We deployed 31 nodes randomly in a flat area of size 50m $\times$ 50m, including 1 source, 1 destination, and 29 intermediate nodes. Source and intermediate nodes are moving following the Random Waypoint mobility model. The source node generates constant bit rate UDP packets with a default rate of 2 packets/s. A classic CSMA implementation from Castalia has been chosen as the MAC protocol, and an irregular radio module from Castalia has been used. A nominal transmission range of 11 m is set by tuning the physical layer parameters, such as transmission power and receiver sensitivity. Each simulation runs for 300 s, and the results are averaged over 30 simulation runs with different random-generated seeds to provide a confidence interval of 95%. Table I shows the baseline simulation parameters.

Parameter	Value	Parameter	Value
Data rate	2 Packet/s	Radio model	CC2420
BS location	(48,48)	Source location	(5,5)
Node density	31	Transmission power	-10 dBm
Node speed	5 m/s	Path loss model	Lognormal
Node pause	30 s	DFD_{max}	0.1 s

TABLE I
Default simulation parameters

B. COR Parameters

As shown in Eq. (1), COR selects a forwarder based on four types of context information: *link quality*, *progress*, *residual energy*, and *LIVE*, in which *link quality* and *progress* are conflicting indeed. This is because considering *progress* means the source prefers the node making the largest progress. However, considering *link quality* implies that the source chooses the neighbor with the best channel quality, which is often the closest neighbor. In general, optimizing all parameters will not be possible, instead we should achieve a trade-off between multiple contexts. Therefore, first we analyze which combination of context weights produces the best result.

We defined 14 combinations with different values for $\alpha, \beta, \gamma, \delta$, as shown in Table II, to demonstrate the importance of considering multiple contexts. To highlight the usefulness of considering mobility relevance, we divide the combinations into two groups: one group does not consider *LIVE* (#1 $\sim$ 9 with δ = 0), and the other considers *LIVE* (#10 $\sim$ 14 with δ = 0.3).

Combination #	α (Link Quality)	β (Progress)	γ (Energy)	δ (LIVE)
1	0	0.9	0.1	0
2	0.1	0.8	0.1	0
3	0.2	0.7	0.1	0
4	0.3	0.6	0.1	0
5	0.4	0.5	0.1	0
6	0.5	0.4	0.1	0
7	0.6	0.3	0.1	0
8	0.7	0.2	0.1	0
9	0.8	0.1	0.1	0
10	0.1	0.5	0.1	0.3
11	0.2	0.4	0.1	0.3
12	0.3	0.3	0.1	0.3
13	0.4	0.2	0.1	0.3
14	0.5	0.1	0.1	0.3

TABLE II
COMBINATIONS OF COEFFICIENTS IN FORMULA (1)

Packet Delivery Ratio (PDR) of 14 combinations are presented in Figure 5. We can find out that #1 has the worst performance. This is because it gives almost all weights to *Progress* and therefore ignores *Link Quality* and *LIVE*. Therefore, it always chooses the neighbor with the largest progress as next hop without considering any other information. However, the most distant neighbor has the highest probability of suffering from a bad channel quality and thus may lead to high packet loss. With more balanced weights of *Link Quality* and *Progress*, the performance reaches a peak at #5 for situations that do not consider *LIVE* (δ = 0). That is also the best performance reached by our previous work of TLG [13], where node mobility is not considered.

Interestingly, we can observe that when mobility relevance is considered ($\delta \neq 0$), the performance improved significantly. This is because when relative mobility of nodes is exploited, a relay candidate with a more favorable movement pattern will be chosen as next hop. This ensures that at each hop a local optimization of candidate selection could be achieved. The best performance is reached at combination #12, which has good balance of weights of *Link Quality*, *Progress*, *Energy*, and *LIVE* ($\alpha = \beta = \delta = 0.3$, $\gamma = 0.1$). This could avoid the occurrence of bad situations, such as choosing a node that is only valid for a very short time; or choosing the most distant neighbor, which has a poor link quality; or choosing the nearest neighbor with small progress. Therefore, we choose this setting of weights when comparing COR against others.

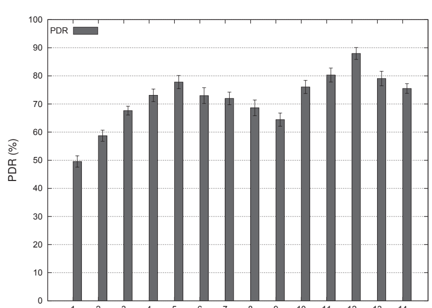

Fig. 5. PDR of 14 coefficient combinations

C. Performance Comparison with BLR and GPSR

To show the superiority of COR over BLR and GPSR, we measure and compare PDR, goodput, and end-to-end delay of the three protocols with different maximum speeds (Figure 6, Figure 9), node densities (Figure 7), and node pause intervals (Figure 8), separately.

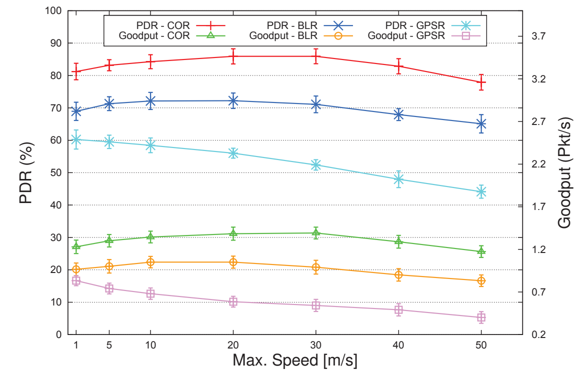

Fig. 6. PDR and Goodput vs. Maximum Speed

Results of Figure 6 show that COR outperforms BLR and GPSR with various speeds. GPSR degrades significantly as speed increases, because it has to maintain neighbor tables and routes, which will be outdated more frequently as speed increases. With an increasing speed, performance of COR and BLR first improve (with speed up to $\sim$ 30 m/s) and then become worse. This is because with low mobility, nodes have higher chances to meet a better forwarder. However, if the speed is too high (>30 m/s), the contact duration between two nodes is too short and the links break frequently, which reduces performance. This is more severe for COR, due to its dependence on the link validation. COR outperforms BLR, since it uses various context information to choose a forwarder, while BLR always chooses the most advanced neighbor such that it has a higher chance to suffer from a bad radio link.

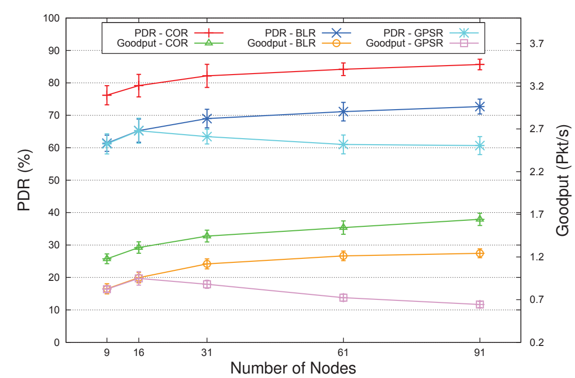

Fig. 7. PDR and Goodput vs. Node Density

Figure 7 shows the performance of the three protocols under different node densities. PDR and goodput of COR and BLR increase with network density. This might be due to two reasons: first, the number of available paths increases with the average number of a node's neighbors, which makes the protocols more robust against failures; second, the average path length decreases with node density, since a node has a higher chance to find a near-optimal forwarder, which is the one with the largest progress among the nodes satisfying the LQI requirements. However, GPSR performance degrades for number of nodes > 16 due to the congestion caused by the increased number of control packets. When there are few nodes, the performance values of BLR and GPSR are similar. This is because the packets are frequently routed in backup mode, which is due to temporarily partition of the network.

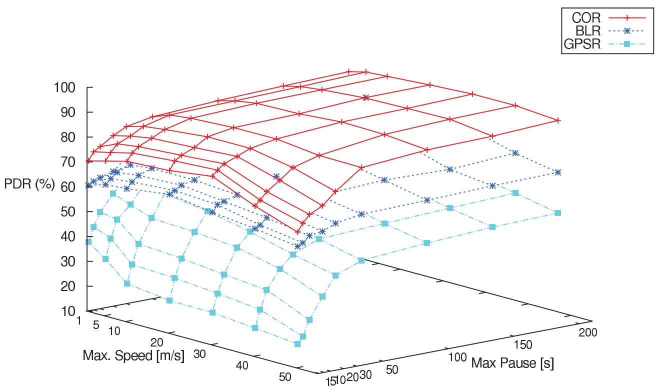

Fig. 8. PDR vs. Max. Speed vs. Pause time

Figure 8 presents the PDR of the three protocols with different speeds and pause intervals. With a long pause interval, COR performs very well even at high speeds, which is due to its high dependence on the link duration. Given a long pause time, the link disruption rate of mobile nodes using the Random Waypoint model is low, which facilitates the calculation and usage of *LIVE*. When the pause time is short and the speed is high, COR performance degrades a bit due to the frequent link breaks. In general, COR performs better than BLR, due to its consideration of multiple types of context information. GPSR performs bad when pause time is short, since the neighbor tables will be outdated more frequently.

Delay results of the three protocols are shown in Figure 9. BLR and COR have only a fraction of the average end-to-end delay compared to GPSR. This is mainly due to two reasons: first, the opportunistic routing approach allows packets to reach the destination via fewer hops; second, GPSR suffers from frequent link breaks due to node mobility, where it has to search for new route. Therefore, delay of GPSR increases as node speed increases. COR has a longer delay than BLR. This is because COR does not choose the most distant node as the forwarder, which means the packet has to go through more hops before reaching the destination. Therefore, a slightly longer delay is observed for COR.

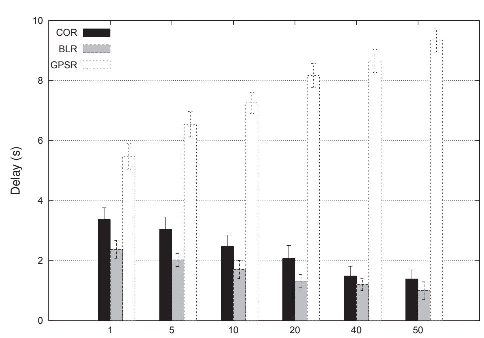

Fig. 9. Average End-to-End Delay vs. Maximum Speed

V. Conclusions

Constantly changing topologies of MANETs makes conventional opportunistic routing, which is based on a pre-calculated candidate list using single metrics, unable to provide satisfactory performance. Inspired by beacon-less geographical routing, we propose and evaluate a novel OR protocol: COR - Context-aware Opportunistic Routing protocol for MANETs. The contributions of COR are threefold. First, it simultaneously uses various context information such as link quality, geographic progress, and residual energy of nodes to make routing decisions. Second, it allows all qualified nodes to participate in packet forwarding. Third, it incorporates the relative mobility of nodes to further improve performance. Simulation results show that COR performs best and could improve PDR and goodput by nearly 20 - 40 % compared to previous approaches that rely solely on a single metric. Future works will include the analysis of duplicate transmission.

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