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An Efficient Context-aware Opportunistic Routing Protocol

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Abstract - Opportunistic routing is designed for an environment where there is no stable end-to-end routing path between source node and destination node, and messages are forwarded via intermittent contacts between nodes and routed using a store-carry-forward mechanism. In this paper, we consider PRoPHET(Probabilistic Routing Protocol using History of Encounters and Transitivity) protocol as a base opportunistic routing protocol and propose an efficient context-aware opportunistic routing protocol by using the context information of delivery predictability and node type, e.g., pedestrian, car, and tram. In the proposed protocol, the node types of sending node and receiving node are checked. Then, if either sending node or receiving node is tram, messages are forwarded by comparing the delivery predictability of receiving node with predefined delivery predictability thresholds depending on the combination of sending node and receiving node types. Otherwise, messages are forwarded if the delivery predictability of receiving node is higher than that of sending node, as defined in PRoPHET protocol. Finally, we analyze the performance of the proposed protocol from the aspect of delivery ratio, overhead ratio, and delivery latency. Simulation results show that the proposed protocol has better delivery ratio, overhead ratio, and delivery latency than PRoPHET protocol in most of the considered simulation environments.

Key Words : opportunistic routing protocol, context, node type, delivery predictability

1. Introduction

Opportunistic routing is designed for an environment where there is no stable end-to-end routing path between source node and destination node. In opportunistic routing, messages are forwarded via intermittent contacts between nodes and routed using a store-carry-forward mechanism [1]-[3], i.e., nodes store messages in their buffers, carry them when they move, and finally forward them to other nodes when the forwarding conditions are met. Opportunistic routing has been developed for possible uses in disconnected network scenarios, such as for extreme cases such as disaster environments and interplanetary communications in deep space.

Representative examples of opportunistic routing protocol are Epidemic, Spray & Wait, and PRoPHET(Probabilistic Routing Protocol using History of Encounters and Transitivity), and they are mainly proposed for networks allowing delay/disruption tolerant message delivery. In Epidemic protocol [4], messages are flooded opportunistically to all nodes which are contacted intermittently, as the name “epidemic” implies. Epidemic protocol works well when the buffer size of nodes is sufficient but results in high overhead when the buffer size is not sufficient, especially for mobile nodes. Spray & Wait protocol [5] was proposed to alleviate the high overhead of Epidemic protocol by limiting the total number of message copies of a generated message by L. In Spray phase, L copies of a message are distributed to L-1 other nodes. Then nodes with a single copy of the message go into Wait phase and forward the message only to a destination node of the message.

In PRoPHET protocol [6], context information of delivery predictability is derived based on contact history between nodes. Then, when two nodes contact, messages are forwarded to a node with higher delivery predictability to the destination nodes of the messages. PRoPHET protocol is different from early mentioned Epidemic and Spray & Wait protocol, which forward messages blindly, in a sense that it uses context information such as delivery predictability derived from contact history between nodes for message forwarding, and lots of attention have been paid to opportunistic routing protocols using context information.

In [7], data packet is classified by either Q-packet or R-packet based on the context of quality of service (QoS)

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requirement in sparse mobile sensor networks with a small number of neighbors, where Q-packet requires low delivery delay and R-packet requires high reliability. In [7], the authors support heterogeneous QoS requirements of Q-packet and R-packet by allocating more bandwidth for Q-packet and more storage for R-packet. In [8], the authors use the context of proximity in by constructing social community group. They combine contexts of space and time with contacts between users, construct an influence graph, and derive context-aware community structure using the influence graph.

Recently, a lot of works on using transportation systems, which is related to our works in this paper closely, have been carried out [9]-[16]. In [9], the authors consider vehicular delay tolerant networks (VDTN), where connectivity between vehicles is not guaranteed in vehicular ad hoc networks (VANET), and messages are delivered by vehicles using a store-carry-forward mechanism. In [9], the authors place relay nodes with high capacity of storage in strategic positions, and use them efficiently to exchange messages between vehicles. Then, they formulate an optimal placement of relay nodes using integer linear programming and develop heuristic algorithms to solve the optimization problem. In [10], the authors propose a solution for mobile delay/ disruption tolerant network (MDTN), which is DTN application platforms implemented using a public transportation system to cover areas with no Internet coverage. In [10], requests by mobile users are delegated by access points in public transportation systems and they are delivered to Internet gateways located at bus line terminals. Finally responses are successfully delivered to the bus line indicated by mobile users when they placed requests.

In [11], the authors propose bus switched network (BSN), which is a kind of opportunistic network using buses in a city environment and prove that BSN can achieve high delivery ratio and acceptable delays. In [12], the authors analyze contacts between buses based on the real traces taken from UMass DieselNet [13], which is a bus-based disruption tolerant network consisting of access points attached to buses. They found that inter-contact times between buses aggregated at a route level shows a periodic behavior and constructed route-level connection model.

In [14], the authors propose data MULE, where sensor data are collected by mobile nodes called MULEs and delivered to wired access points by MULEs. With the help of the data MULE, power of sensor nodes can be saved significantly. In [15], the authors propose message ferries in a sparse mobile ad hoc network and use them to provide communication service for nodes. Message ferries have non-random movement pattern and thus, this information can be used by nodes to deliver message to ferries. In [16], the authors propose Postbox which can receive message from directly connected nodes and messages can be delivered using stable connection between Postboxes.

In this paper, we consider PRoPHET protocol as a base opportunistic routing protocol and propose an efficient context-aware opportunistic routing protocol by using the context information of delivery predictability and node type, e.g., pedestrian, car, and tram. We show that the proposed protocol has better delivery ratio, overhead ratio, and delivery latency than PRoPHET protocol in most of the considered simulation environments by using simulation.

The remainder of this paper is organized as follows: Section 2 proposes the proposed routing protocol in detail and the performance of the proposed protocol is analyzed in Section 3 using simulation. Finally, Section 4 concludes this work.

2. Proposed Routing Protocol

In the proposed routing protocol we consider context information of both delivery predictability and node type for the decision of message forwarding,. In this paper, node type is classified into pedestrian, car, and tram as assumed in opportunistic network environment (ONE) simulator [17], [18]. The basic idea of the proposed protocol is to give higher priority for message forwarding to tram, since tram can have enough buffer memory and runs along a predefined line, and thus accommodate more messages and is highly likely to have more chances to forward messages to destinations. Figure 1 shows scenarios for message delivery in the

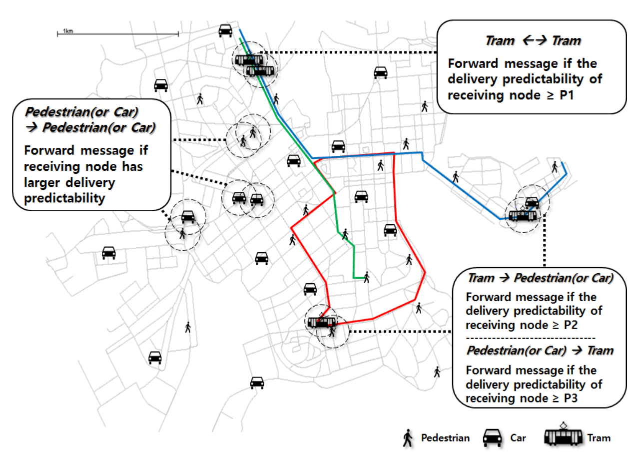

Fig. 1 Scenario of the message delivery in proposed routing protocol.

proposed routing protocol.

Figure 2 shows a flowchart of the proposed protocol. When two nodes meet each other they exchange summary vectors which include the list of messages they have. Depending on the types of sending node and receiving node, different message forwarding criterion is applied. If sending node and receiving node are trams, message is forwarded if the delivery predictability of the receiving node is not smaller than P1, where P1 is generally set as a very small value to give higher priority for message forwarding to tram. If sending node is tram and receiving node is not tram, message is forwarded if the delivery predictability of the receiving node is not smaller than P2, where P2 is generally set as a very high value, since pedestrians and cars do not have enough buffer memory and thus, need to limit the message forwarding. If sending node is not tram and receiving node is tram, message is forwarded if the delivery predictability of the receiving node is not smaller than P3, where P3 is generally set as a very small value to give higher priority for message forwarding to tram but P3 can be set as different value from P1. If both sending node and receiving node are not tram, message is forwarded if the delivery predictability of receiving node is higher than that of sending node, as defined in PRoPHET protocol.

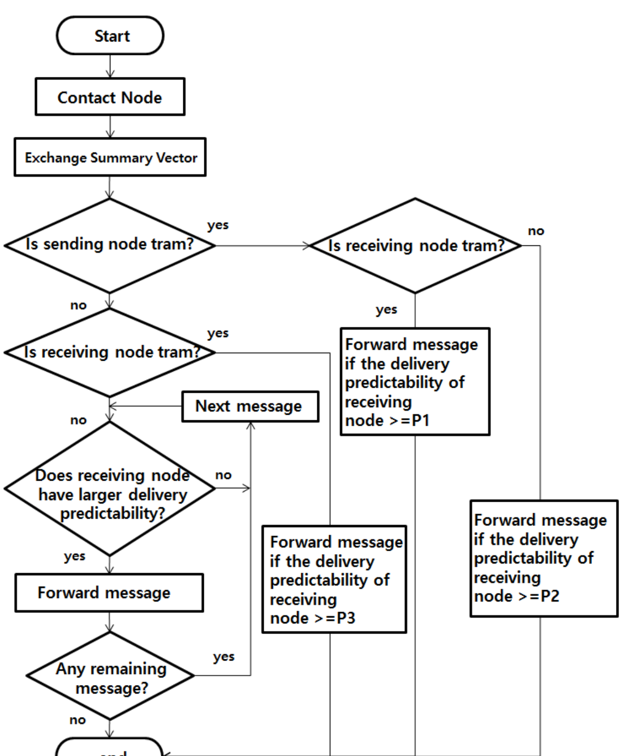

Fig. 2 Flowchart of the proposed protocol.

The proposed routing protocol is similar to data MULE [14], message ferry [15], or Postbox [16] protocol in a sense that nodes with rich resources act as a message carrier. However, in data MULE or message ferry, message forwarding is carried out only via data MULE or message ferry but there is no direct message forwarding between other nodes. But, messages can be forwarded between nodes other than tram directly using intermittent contacts in the proposed protocol. In Postbox protocol, nodes are directly connected with neighbor Postbox always and there is stable connection between Postboxes. However, contacts between trams, and between tram and other nodes occur intermittently in the proposed protocol and there is no stable connection between them. Other differences between the proposed protocol with data MULE, message ferry and Postbox are that tram also can generate message as well as forward message in the proposed protocol, and message delivery between nodes is carried out using context information such as delivery predictability and node type in the proposed protocol.

3. Performance Analysis

In this paper, we analyzed the performance of the proposed context-aware routing protocol using ONE simulator and the assumed values of simulation parameters are given in Table 1.

To analyze the effect of buffer size of pedestrian and car on the performance of the proposed protocol, we obtained delivery ratio, overhead ratio, and delivery latency in Figs.

Table 1. Values of simulation parameters

Parameter	Value
Simulation Times(s)	432,000
Aging constant	0.98
Movement Model	pedestrian, car: Shortest Path Map Based Movement tram: Map Route Movement
Transmit Range(m)	30
Packet Transmission Speed(Kbyte/s)	250
Number of Hosts	129 (pedestrian: 80, car: 40, tram: 9)
Message Interval(s)	U[25,35]
Message Size(Bytes)	U[500k,1M]
Buffer Size(Bytes)	pedestrian, car: (10M, 20M, ⋯, 100M) tram: 1,000M
Delivery Predictability Threshold	P1=0, P2=1, P3=0

3~5. Figure 3 shows the delivery ratio for varying the buffer size of pedestrians and cars, where the buffer size of tram is assumed as 1GBytes and delivery ratio is defined as follows:

$$Delivery\ ratio = \frac{total\ number\ of\ delivered\ messages}{total\ number\ of\ generated\ messages} \quad (1)$$

As shown in Fig. 3, the delivery ratios of both protocols increase as the buffer size of pedestrians and cars increase, since larger buffer size accommodates more messages and thus, results in more message delivery than smaller buffer size. The proposed protocol has higher delivery ratio than PRoPHET protocol, since the proposed protocol can deliver messages to destinations better by using tram as a message carrier efficiently.

Figure 4 shows the overhead ratio for varying the buffer size of pedestrians and cars, where the buffer size of tram is assumed as 1GBytes and overhead ratio is defined as follows:

$$Overhead\ ratio = \frac{(total\ number\ of\ forwarded\ messages - total\ number\ of\ delivered\ messages)}{total\ number\ of\ delivered\ messages} \quad (2)$$

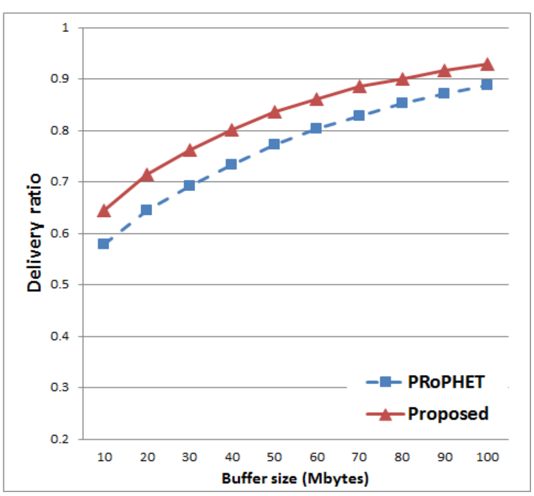

Fig. 3 Delivery ratio for varying the buffer size of pedestrians and cars.

As shown in Fig. 4, the overhead ratios of both protocols decrease as the buffer size of pedestrians and cars increase in most of buffer size values because of increased number of delivered messages for large buffer size. The proposed protocol has lower overhead ratio since the total number of delivered messages, i.e., the denominator of Eq. (2), is higher in the proposed protocol and thus, overhead ratio is smaller in the proposed protocol.

Figure 5 shows the delivery latency for varying the buffer size of pedestrians and cars, where the buffer size of tram is assumed as 1GBytes and delivery latency is defined as follows:

$$Delivery\ latency = \frac{total\ sum\ of\ delivery\ latency\ of\ all\ delivered\ messages}{total\ number\ of\ delivered\ messages} \quad (3)$$

As shown in Fig. 5, delivery latency of both protocols increases as the buffer size increases since larger buffer size accommodates more messages and thus, results in longer message delivery latency. The proposed protocol has

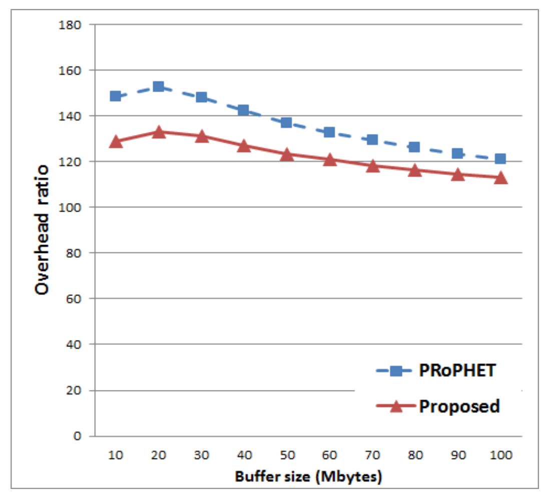

Fig. 4 Overhead ratio for varying the buffer size of pedestrians and cars.

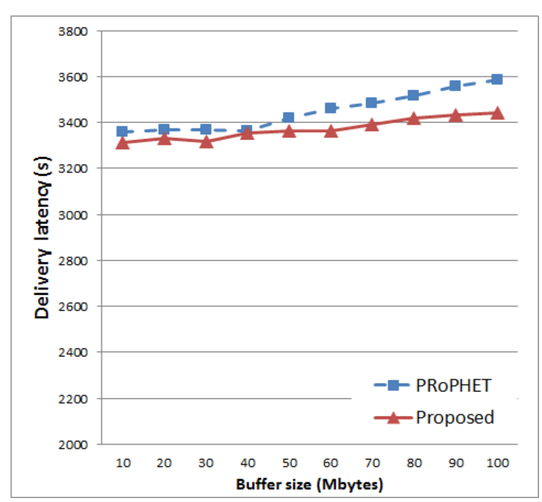

Fig. 5 Delivery latency for varying the buffer size of pedestrians and cars.

lower delivery latency, since messages can be delivered more quickly using tram as a message carrier efficiently and thus, average delivery latency of the proposed protocol is smaller than PRoPHET protocol.

To analyze the effect of message intervals on the performance of the proposed protocol, we obtained delivery ratio, overhead ratio, and delivery latency in Figs. 6~8, for varying the message interval with uniform distribution with boundary values denoted in x-axis, where buffer size of pedestrian and car is 20 Mbytes and buffer size of tram is 1,000 Mbytes.

Figure 6 shows the delivery ratio for varying the generated message intervals. As shown in Fig. 6, delivery ratios in both proposed and PRoPHET protocol increase as the message interval increases since fewer messages are generated for larger message interval, and thus, fewer

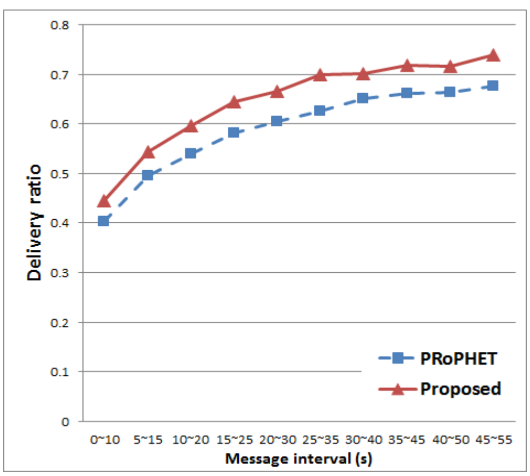

Fig. 6 Delivery ratio for varying the message interval.

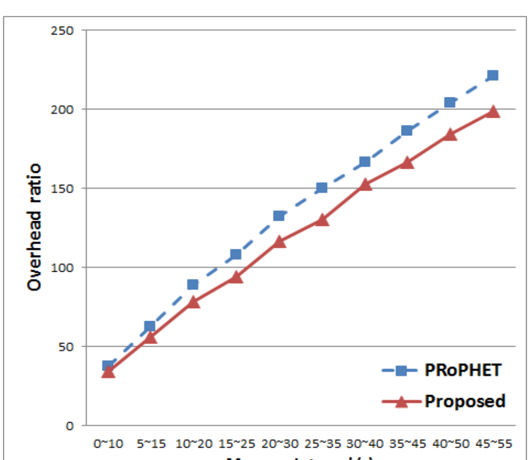

Fig. 7 Overhead ratio for varying the message interval.

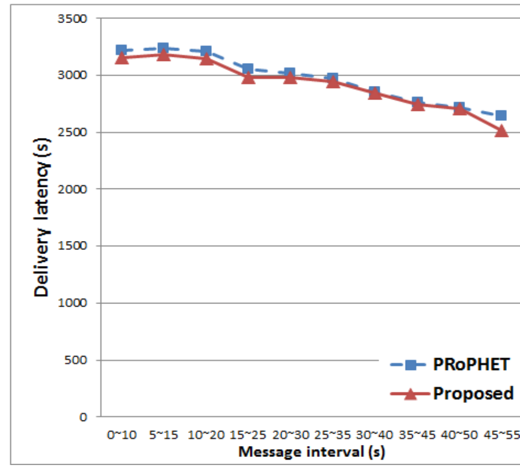

Fig. 8 Delivery latency for varying the message interval.

messages are dropped due to buffer overflow and the ratio of successfully delivered messages is higher. The proposed protocol has higher delivery ratio than PRoPHET protocol, since the proposed protocol can deliver messages to destinations better by using tram as a message carrier efficiently for various message intervals.

Figure 7 shows the overhead ratio for varying the generated message intervals. As shown in Fig. 7, the overhead ratios of both protocols increase as the message interval increases because of smaller number of delivered messages. The proposed protocol has lower overhead ratio since the number of delivered messages itself, i.e., the denominator of Eq. (2), is higher in the proposed protocol and thus, overhead ratio is smaller in the proposed protocol.

Figure 8 shows the delivery latency for varying the generated message intervals. As shown in Fig. 8, delivery latency of both protocols decreases as the message interval increases since larger message interval generates smaller messages and thus, results in shorter message delivery latency. The proposed protocol has slightly lower delivery latency, since messages can be delivered more quickly using tram as a message carrier efficiently and thus, average delivery latency of the proposed protocol is smaller than PRoPHET protocol.

4. Conclusions

In this paper, we proposed an efficient context-aware opportunistic routing protocol by using the context information of delivery predictability and node type. Then, we analyzed the performance of the proposed protocol from the aspect of delivery ratio, overhead ratio, and delivery latency, for varying the buffer size of pedestrian and car, generate message interval, and buffer size of tram, using ONE simulator. Simulation results show that the proposed protocol has maximum 8% delivery ratio increase, maximum 15% overhead decrease, and maximum 3% delivery latency decrease compared to PRoPHET protocol in the considered simulation environment, and this shows that the proposed protocol works efficiently by using tram as a message carrier.

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