PAPER

Introduction of the Parameter "Approach Ratio" for the Improvement of Higher Delivery Rate with Suppressing Network Resource Consumption in Delay Tolerant Network

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SUMMARY The delay/disruption tolerant network (DTN) has been researched actively in the last years because of its high applicability to ubiquitous network services such as sensor networks and intelligent transport system (ITS) networks. An efficient data forwarding method for those network services is one of the key components in DTN due to the limitation of wireless network resources. This paper proposes a new DTN scheme for vehicle network systems by introducing the parameter, "approach ratio", which represents node movement history. The proposal utilizes passive copy strategy, where nodes within one hop area of packet forwarders receive, copy and store packets (namely, passive copies) for future forwarding, in order to obtain higher delivery rate and lower delivery delay whilst suppressing the network resource consumption. Depending on its approach ratio, a node with passive copy decides whether it forwards the passive copy or not by referring to the approach ratio threshold. The approach ratio allows our proposal to adjust the property of both single-copy type scheme, that can lower network resource consumption, and multi-copy type scheme, that can enhance the performance of delivery rate and delay time. In simulation evaluation, the proposal is compared with three typical existing schemes with respect to network consumption, delivery rate and delivery delay. Our proposal shows the superior performance regarding the targeted purpose. It is shown that the approach ratio plays the significant role to obtain the higher delivery rate and lower delay time, while keeping network resource consumption lower.

key words: *mobile ad hoc network, DTN, passive copy, network resource, delivery rate*

1. Introduction

During the past years, many research and development activities have been carried out in mobile ad hoc networks (MANETs). MANETs are infrastructure-less, where nodes organize a network dynamically by themselves by wireless communication. To realize such dynamic networks, many routing protocols have been proposed for MANETs, such as OLSR [1], TBRPF [2], AODV [3], DSR [4], DYMO [5], and so on. In all these routing protocols, it implies the assumption that a network is always connected and it has a contemporaneous end-to-end path between a certain pair nodes. However, in an actual mobile network, such an assumption is not always guaranteed. When nodes are in motion, intervening obstacles, changes of radio signal levels, or isolation from other nodes, will disturb communication and break links, which results in intermittent connectivity of a network. However, if we could accept longer packet transmission delay, another kind of network could be established, in that way that an end-to-end connected path is not always necessary. Such a kind of network is called as disruption/delay tolerant network (DTN). In DTN, nodes can communicate over intermittently connected links accepting some delay. The research of DTN becomes active these years [6]–[11]. The tolerable delay in DTN could be from seconds to one week or more.

To cope with intermittent connectivity, one natural approach is to extend the scheme of store-and-forward routing to store-carry-forward (SCF) routing. In SCF routing, the next hop node to forward a packet may not be immediately available. Therefore, a node must be capable of buffering packets for a considerable duration. Once a node encounters a next hop node in its range of radio communication, it forwards buffered packets to the next hop node. Routing here consists of independent and local forwarding decisions, determined by current connectivity information and prediction of future connectivity etc. The difficulty in designing a protocol for efficiently and successfully delivering packets to the destinations is to determine, for each packet, the best node and timing to forward packets.

A number of existing opportunistic SCF routings are categorized into two types, i.e. single-copy type and multi-copy (or flooding-based) type. This categorization comes from a view of the number of nodes selected as next hop in forwarding a packet. In single-copy schemes, there is only one node in a network that carries a copy of packet at any given time. On the other hand, multi-copy routing schemes may generate multiple copies of the packet, which can be routed via two or more nodes for increased robustness.

Single-copy schemes that only route one copy per packet can considerably reduce resource waste [10]–[12], although they result in less reachability, larger delay, and inherently less reliability and robustness than multi-copy schemes. Most of the multi-copy type protocols developed are flooding-based where duplicate copies are disseminated to all nodes in a network [13], [14] or a subset of them [15],

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[16]. Despite their increased robustness and low delay, this type of the protocols consumes the large amount of energy, bandwidth and memory space. Furthermore, under high traffic load condition they suffer from severe contention and packet collision, and consequently their performance significantly deteriorates. These drawbacks cause inappropriateness for bandwidth-constrained environment with many nodes such as in a vehicle network.

To summarize, almost no routing scheme for DTN can achieve cautious and moderate usage of network resources, high reachability and small delay simultaneously.

In this paper, we propose a new routing protocol based on the single-copy SCF (S-SCF) scheme, for especially stressing on the invaluableness of network resources, intended for vehicle network systems where nodes, i.e. cars have high mobility and their topology is stochastic and unpredictable. The proposed method takes advantages of both single-copy and multi-copy schemes through introduction of a new parameter "approach ratio" that implies movement history of a node and determines packet forwarding timing at an intermediate forwarding node. We evaluate the performance of the proposal in terms of wireless network resource consumption and delivery rate and delay by comparing with typical existing schemes through simulation over a vehicular network scenario. Then how the proposed scheme adjusts the tradeoff performance by the parameter of "approach ratio" is presented and shown to yield lower network resource consumption, higher delivery rate, and lower delay.

The network resource consumption in this paper, which is defined by the number of radio emission in networking data packet to its destination, is essential metrics in terms of how efficiently radio network resource can be utilized. Because the radio network resource is allocated with strict limitation. For example, only one or two channels with 10 MHz bandwidth in Japan and Europe are regulated especially for traffic safety related use-cases. Nevertheless, the resource should be available to a large number of vehicles at the same time such as in traffic congestion.

There is still other important metrics such as buffer size or power consumption etc. in SCF system. However, with regard to the buffer, it has more flexibility than radio network resource for vehicle network system, in a way that it can be deployed nowadays in proper quantity with low cost through its prior estimation. In case, it could be extended or replaced accordingly. With regard to the power consumption, it isn't of much importance at present due to current practical capability of sustainable power supply during driving, although in the future, when electric vehicles become popular, electric power consumption may require consideration. This paper, hence, takes the network resource as the first priority. It is noted here that security issues are out of scope in this paper, even though it would be critical in the real system.

This paper is organized as follows. In the next section, we mention some existing related work, which will be used in the evaluation section for comparison purposes. In Sect. 3, the proposed method is described in detail. Then results of performance evaluation are explained in Sect. 4. Finally we conclude this paper and future works are shown in Sect. 5.

2. Related Works

There exists a growing amount of work on stochastic DTN routing protocols, which can be classified into two types, single-copy and multi-copy schemes as described in chapter 1. With regard to the single-copy scheme, in GPRS protocol [10], a node having a packet tries to forward it to a next hop node chosen according to the Most Forwarding Progress strategy (MFP), i.e. to choose the neighbor node closest to the destination. Sometimes, though, this strategy may lead to a local maximum for its greediness. The strategy has been proven to be successful for static or very slowly dynamic networks. KNOF [11], VADD [17], MHVB [18] and MOPR [19], which are specifically designed for vehicular networks, make use of node geographical information and prediction. Packet transmission is controlled by a certain function of various parameters such as velocity, direction and position of nodes. In Utility based protocol [12], each node maintains a timer for every other node in a network to record the time elapsed since it encountered the node. The routing algorithm allows a node with a single copy to hand it over to another node chosen based on the value of the utility function, which is defined taking into account its encounter.

With regard to the multi-copy scheme, Epidemic Routing (ER) [13], [14] is a simple protocol which is quite similar to flooding. It assumes that nodes have inexact knowledge of other nodes' positions. Hence, any sent packets are disseminated through a network to maximize the delivery probability and minimize delivery delay without geographical information. ER has been proven to be efficient in very scarce networks where the encounters between nodes are rare. In order to alleviate redundancy of flooding of ER, the article [16] studies several schemes for decision of the timing and the best node of re-flooding based on geographical information assumed with a positioning system. PROPHET [15] assumes that the movement in an ad-hoc network has repeating behavioral patterns, which are predictable, such that if a location has been frequently visited to in the past, it is likely that it will be visited again in principle in the future. PROPHET makes use of this observation to improve routing performance by a probabilistic metric called delivery predictability that indicates the predicted chance of next node delivering a packet to the destination.

In summary, single-copy type schemes that only route one copy per packet can considerably suppress the waste of network resources. KNOF and Utility based protocol have the same strategy of selecting node for the next forwarding node based on values of a defined function based on current geographical and encounter information respectively. GPSR does not take advantage of node mobility and never uses the store-carry-forward (SCF) strategy. Hence, it leads to less reachability, higher delay, and inherently less reliable than KNOF and Utility based protocol. Multi-copy type schemes which adopt flooding-based dissemination generate duplicate packets in general. Therefore, they are, even if carefully tuned, prone to the same shortcomings. That is, despite their increased robustness and the lower delay, flooding-based protocols consume the large amount of energy and bandwidth leading to significant degradation of the performance and scalability.

3. Proposed Scheme

The proposal has advantages of both multi-copy and single-copy schemes and it can adjust its behavior and performance according to application requirements by introducing a parameter “approach ratio”. This parameter is unique from existing schemes in respect that it utilizes not only present but also past geographical information, i.e. movement history by which we expect efficient and higher reachability of data packet.

In the following, we give description in detail of our proposal, firstly, starting with the basic behavior of single-copy type SCF (S-SCF) method, followed by introduction of the parameter “approach ratio” and the “passive node” concept.

3.1 Basic Forwarding Scheme

Figure 1 illustrates time evolving behavior of S-SCF routing in delay tolerant networks. In Fig. 1 there is no direct path from node S (Source) to node D (Destination) at any given time. Mobile nodes move around, and intermittent connection among them may appear occasionally.

A packet generated at node S is transmitted to node D by mediation of other mobile nodes which receive, store, and forward the packet to another node chosen as the best next forwarding node or the final destination D. At time T0, source node S, nodes 1, 2, and 4 form an ad hoc network, i.e. a connected graph. Node S chooses the best next forwarding node, e.g. node 4, among the nodes in the ad hoc network, by comparing certain function values described in detail afterwards. Then, the packet is sent from node S to node 4 via node 1. Node 4 moves towards its destination holding the received packet. At time T1, node 4 comes to form another ad hoc network with nodes nearby. Node 4 plays the role of a tentative source node to choose node 5 as the next forwarding node and passes the packet to it. Similarly, at time T2, nodes 3, 5, and D occasionally form an ad hoc network and the packet finally reaches to the destination node D.

3.1.1 The Forwarding Node

How a node operates is explained here after it was chosen as the forwarding node in the previous section. Whenever the forwarding node encounters other nodes, the node checks if there is more suitable node as a next forwarding node than itself through the given selection method. Then if not, the current forwarding node continues to play the same role keeping the packet until the next encounter. If yes, it chooses that node as the next forwarding node and it routes the packet to the chosen one. In Sect. 3.3, the proposed selection method is described.

3.2 Introduction of “Approach Ratio”

The proposal is derived from the viewpoint of how S-SCF can acquire the characteristics of multi-copy scheme, which can expect high reachability and low delay, while keeping low radio network consumption. The process of two steps is added to the basic S-SCF operation.

Step (1): Transition to a “passive node”
Because of the nature of wireless communication, one-hop neighbors of the node broadcasting a packet can hear the packet. In our proposal, they store the heard packet in their cache buffer. The stored packet is called a “passive” copy and the node having a passive copy is called “passive node”. On the other hand, a node holding and transmitting a packet in the basic SCF process is called “active node”. We should note here that the node which has finished sending a packet to its next forwarding node becomes also a passive node. For example in Fig. 2, nodes A, C, and F are passive nodes by hearing the packet transmitted by node G through node B. In addition, nodes G and B also become passive nodes that continue to hold the copy of sent packet after they have sent the packet out to another node. Only node E is an active node at the timing when node E received the packet prepared for the next forwarding. With the step (1), S-SCF can prepare multiple copies at passive nodes which would be future

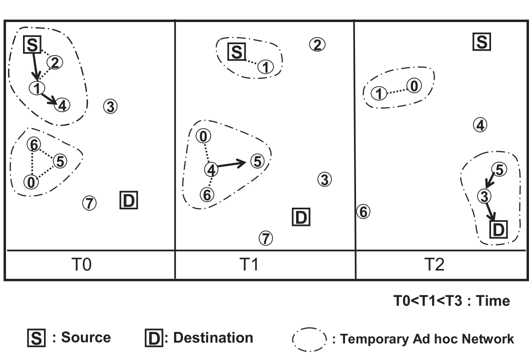


Fig. 1 Packet forwarding in single-copy type scheme.

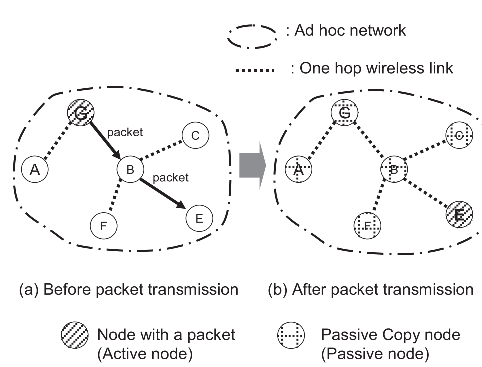


Fig. 2 Passive node and active node.

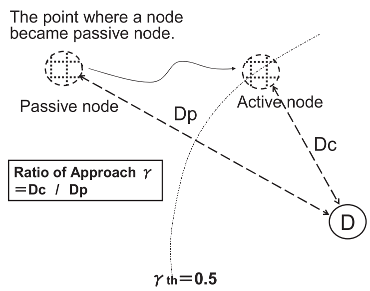


Fig. 3 Approach ratio (γ).

active nodes.

The followed step (2) provides the idea of how a passive node becomes to be an active node by introducing the approach ratio.

Step (2): Transition to an active node by the parameter "approach ratio"
A passive node does not directly contribute to packet delivery unless it actively sends a passive copy to another node. In our proposal, a passive node calculates its own approach ratio (γ) to the destination. When the value of γ is smaller than the predetermined threshold γ_{th}, the passive node switches itself to be active and then is capable of forwarding its passive copy toward the destination. The approach ratio is defined in Eq. (1) and Fig. 3.

$$\gamma \equiv D_c/D_p \tag{1}$$

where D_p is the distance between the position where a node became "passive" and the destination D. D_c is the distance between the current position and the destination. In case that an active node moves off to the destination as $\gamma > 0.5$ (see Fig. 3), it becomes a passive node again.

The approach ratio expresses how much a node approaches to its destination from the point of its becoming passive, or to what degree node's movement history indicates its greediness of approaching toward the destination.

By introduction of the approach ratio, relative position of being active is essential and adjustable. Only the greedy nodes that move nearer to their destination could be chosen as future forwarders. With setting larger threshold, a passive node becomes an active node and brings multi-copy effect at an earlier stage leading to higher reachability and larger overhead. Another approach of the ratio definition, to be sure, could be considered, for example, by setting the fixed area around the destination for becoming active node. However, with such definition, there might be too many active nodes containing non-greedy nodes around the destination and redundant transmissions occur when node density is high such as in city area.

With the step (2), S-SCF gains capability to transit to multi-copy scheme under given condition of the approach ratio in order to obtain multi-copy effect. Thus approach ratio is a practical parameter so that it enables to balance the tradeoff of the multi-copy effect between the waste of network resources and the packet reachability to the destination.

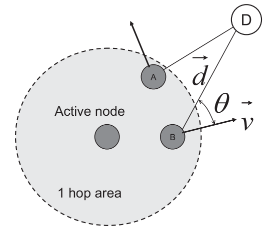


Fig. 4 Selection of next forwarding node.

3.3 Selection Method of the Forwarding Node

In addition of the introduction of approach ratio, the proposal utilizes the function $f_p(\vec{d}, \vec{v})$ defined as Eq. (2) for example in order to choose the next forwarding node, which contains plural geographical parameters by which present node's movement can be defined.

$$f_p(\vec{d}, \vec{v}) = (c + \cos\theta)\frac{Vm + \left\|\vec{v}\right\|}{\left\|\vec{d}\right\|^{\delta}} \tag{2}$$

Figure 4 illustrates Eq. (2), where θ is an angle between $\vec{v}$, i.e. a velocity vector, and $\vec{d}$, i.e. direction vector toward the destination from node B. $c > 1$, $V_m > 0$ are control parameters. The parameter c is introduced to avoid $f_p = 0$ for the angle θ, 270 degree. When c is larger, the influence by the angle is smaller. The parameter Vm is introduced to adjust the influence of node velocity. When Vm is small relative to node velocity, the function value will get directly influenced. The parameter δ is introduced to adjust the effect of the distance between node and destination. When δ is larger, the effect of the distance to its angle and velocity is dominantly given. Those parameters are selected empirically based on the repeated simulation. By choosing a node with the largest f_p value among two-hop neighbors, the packet is expected to be carried to the destination with larger greediness. The parameters of the proposal for following simulation are empirically set as $c = 2$ and Vm =5 m/s, δ= 1.5 for Eq. (2).

3.4 State Transition of the Node

Figure 5 summarizes the state transition of a mobile node. When a normal node is chosen as a next forwarding node and receives data packet, it becomes an active node (transition (1)). On the contrary, a normal node becomes a passive node when it receives a passive copy packet (transition (2)). After an active node sends its packet to the next forwarding node, it becomes passive node (transition (4)). When a passive node moves close to the destination, i.e. its approach ratio γ becomes smaller than the threshold γ_{th}, it becomes an active node and is capable of forwarding passive copy packet (transition (3)). An active node returns to the normal state, when it has finished sending packets to the destination or when the packet lifetime, which is defined as the period

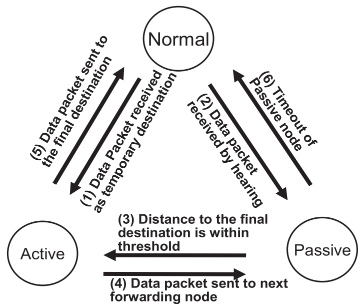


Fig. 5 State transition of node.

of existence in the system from its generation, expires (transition (5)). A passive node deletes a passive copy packet and returns to the normal state when its lifetime expires (transition (6)). It is noted that the state transition is managed for each packet. That is to say, a node can be active for a certain packet whilst the node can be passive for another packet.

4. Evaluation

4.1 Evaluation Method

Through simulation experiments, the proposed scheme is evaluated. The simulator consists of two parts; car traffic part and network part. The car traffic part defines car movement flow, and the network part defines networking model of car nodes

4.1.1 Car Traffic Part

Traffic in the targeted area follows scenarios below;

a) New cars are generated at a given rate. There are plural source/sink points in simulation area. A new generated car randomly chooses a source/sink point. Car velocity is set at random in the range from 8 to 18 m/s.

b) The schedule of traffic lights at intersections follows a given timetable.

c) A route that each car takes is determined in the following way. When a car appears in the region, its destination is randomly chosen among predetermined points. At each intersection, a car calculates, for each possible road r, the number of cars n_r on that road, the size s_r that is defined by road traffic average per day, which is categorized by the regulation, e.g. in Japan into four levels for metropolitan area, and the shortest distance d_r to the destination if that road is taken. A car then chooses the next road which maximizes a function $G(s_r, n_r, d_r)$ value which satisfies the following conditions.

$$\partial G/\partial s_r > 0 \tag{3}$$

$$\partial G/\partial d_r < 0 \tag{4}$$

$$G(s_r, n_r + 1, d_r) < G(s_r, n_r, d_r) \quad \forall (s_r, d_r) \in R^{+^2}, \ \ \forall n_r \in N \tag{5}$$

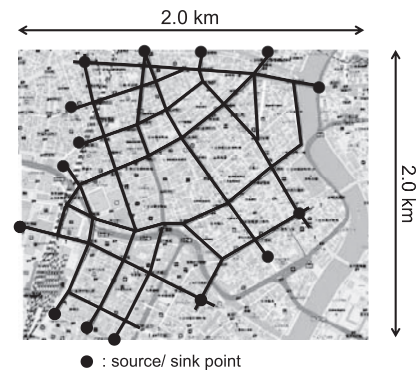


Fig. 6 Road layout.

Conditions (3), (4), and (5) mean that a car prefers a larger road, shorter distance and lower traffic, respectively. $G(s_r, n_r, d_r)$ is then defined as follows.

$$G(s_r, n_r, d_r) = s_r/d_r(n_r + l) \tag{6}$$

with l being an integer that helps reducing the impact of the number of cars when it is low. In case of $l = 0$, a car would always choose an empty road, even if the road goes toward the completely opposite from its destination. In the evaluation, Tokyo station area is chosen as typical city area and implemented its road layout which composes 23 streets, 26 intersections and 15 source/sink points in Fig. 6.

4.1.2 Network Part

The network part defines PHY/MAC and network layer protocols installed for the simulation experiments.

(1) PHY/MAC layer

Assuming IEEE802.11g specification, the following parameters are set. Data rate is fixed at 3 Mbps. The transmission range of wireless radio is 250 meters. Concerning the proposal, all nodes set broadcast mode at MAC layer so that they can hear and receive every data packet exchanged in the vicinity. And the identification of the next forwarding node is set in the payload of MAC frame.

(2) Network layer

The existing three DTN schemes and the proposal are chosen for comparison evaluation. KNOF and Utility based scheme are selected as single-copy type representatives. ER (Epidemic Routing) scheme is selected as multi-copy type representative. The detailed settings of those forwarding schemes are shown in the next section. The function of the proposal is provided including node's position, speed and direction as already shown in Sect. 3.3.

Concerning radio part, only the bandwidth and radio range can be simulated in our simulator, and there is no radio propagation model of varied environments included.

4.2 Performance Results

Our target is to accomplish lower network resource consumption simultaneously with higher delivery rate and lower delay. To this objective, we investigate the performance of schemes in terms of network resource consumption, delivery rate and delivery delay. Cars are generated randomly at given rate, from 10 to 60 cars/minutes. Each car enters into the simulation area from randomly selected source/sink point. Each car generates packets at given constant interval of 10 seconds, whose destination is randomly selected. The packet lifetime is set at 1500 sec. One simulation run lasts for 5300 sec in simulation time unit. Therefore the total number of generated packet is 530 per run. Shown result value is the average of three times repeated simulation runs.

4.2.1 Targeted Criteria of the Performance

We aim at the next generation dynamic traffic information system, where a traffic information center collects cruising information such as the velocity and destination and so on from every car, calculates the current traffic status such as congestion level of each street and traveling time, and sends them back to cars in its service area. As a reference we take, the system in service in Japan, VICS (Vehicle Information and Communication System) system, which collects traffic information via coil loops embedded in roads, refreshes the traffic status every 10 minutes by broadcasting twice gaining 95% or more delivery rate back to the cars via FM radio, beacon etc. The new system aims at the shorter refreshment period, and covers traffic status of every road where vehicles run. Therefore, as target performance criteria, 80% for delivery rate per transmission and refreshment less than 5 minutes (half period of the existing system) are chosen. We assume that the refreshment period of traffic information is within 300 seconds. This means that traffic information is updated every 300 seconds at most and thus the delivery delay should be less than 300 seconds.

4.2.2 Existing Forwarding Methods

KNOF uses several function definitions for next forwarding node selection. In the evaluation we choose the simplest function as given by Eq. (7).

$$f_{KNOF}(\overrightarrow{d}, \overrightarrow{v}) = 1/\left\|\overrightarrow{d}\right\| \tag{7}$$

Concerning Utility based scheme, the following way is applied to choose the next forwarding node. Let each node $i$maintain a utility function $U_i(\cdot)$ for all nodes, and $U_i(i) \geq U_i(j)$, $\forall i, j$. Then, node A forwards to another node Ba packet destined to node D, only if $U_B(D) > U_A(D) + U_{th}$, where U_{th} (utility threshold) is a parameter of the algorithm. In this evaluation, $U_i(\cdot)$ is given by Eq. (8). The timer counts the age of last encounters which represents indirectly relative location information of other nodes.

$$U_i(\cdot) = C_{ij}(\Delta t)/\sqrt{N} \tag{8}$$

where C_{ij} (Δt) is the number of encounters between node i and node j for the preceding duration of Δt, and N is the size of the simulation area [km^2]. It means that a node forwards its data packet to the node with the most frequent encounter during the last given past time.

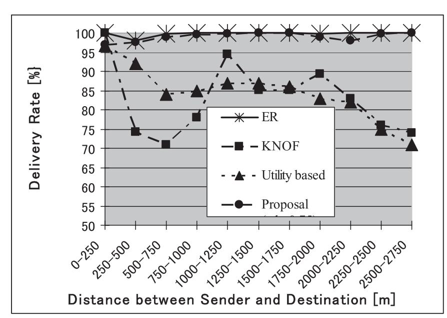
4.2.3 Comparisons

(1) Delivery rate and network resource consumption

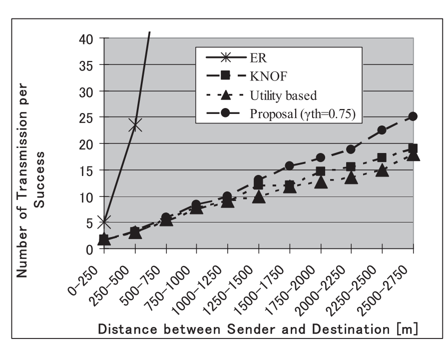
The delivery rate and wireless network resource consumption are evaluated for our proposal and the three existing schemes. The delivery rate is defined as the ratio of the number of packets successfully delivered to their destinations to the number of all packets generated by source nodes. The network resource consumption is calculated as the total number of radio transmission for each data packet, i.e. the number of broadcasting, by all nodes until each packet is delivered successfully. Figure 7(a) shows the relation between the delivery rate and the distance between a pair of source and destination. The delivery rate is averaged over results obtained for each distance segment.

For example, the result where the linear distance between a pair of source and destination is 230 m is categorized into the result of the distance segment of "0 to 250" m.

From a delivery rate perspective, ER has the better performance than expected, where transmission of multiple copies could lead to congestion at wireless network channel and frequent packet losses. On the other hand, the performance of KNOF and Utility based decrease as the distance increases as a trend, which is the fact that single-copy type



(a) Delivery rate vs. distance



(b) Network resource consumption vs. distance

Fig. 7 Delivery rate and network resource consumption. (car traffic = 40 cars minute)

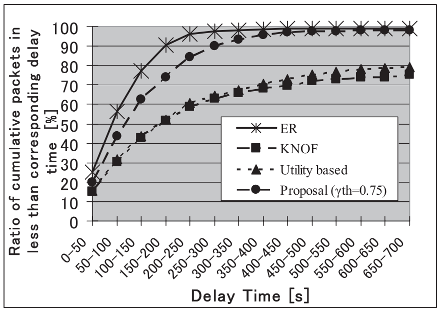
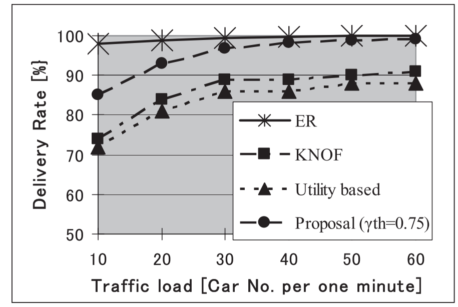
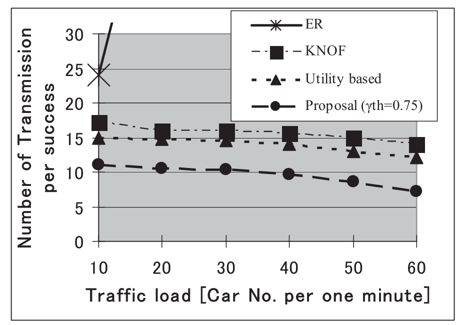


Fig. 8 Delivery delay. (car traffic = 40 cars/minute)



(a) Delivery rate



(b) Network resource consumption vs. traffic

Fig. 9 Influence of car traffic on performance.

has less reachability.

Both KNOF and Utility based schemes have only one path allowed to the destination. Therefore, it can be said accordingly that single path by single copy is more vulnerable to the conditions such as road layout and traffic pattern rather than the function of forwarding node selection. Therefore both single-copy schemes have the tendency that the results deviate from monotonically decrease. It is likely from the results in the distance segment around between 500–1250 m and beyond 2000 m that the distribution of intermediate nodes until the destination becomes sparse.

Our proposal keeps high delivery rate similar to ER. It is because the proposal becomes to acquire characteristics of multi-copy based schemes on the way of forwarding by its state transition according to the value of approach ratio. KNOF and Utility based scheme can provide the delivery rate less than 80% depending the distance. The ER shows the worst performance in terms of the network resource consumption as anticipated (Fig. 7(b)).

The others have a similar tendency except the fact that the proposal has slightly higher network resource consumption due to its multi-copy effect than KNOF and Utility based schemes.

Summarizing the above, our proposal can satisfy the target criteria of 80% delivery rate and still higher while suppressing the network resource consumption as low as the single-copy schemes.

(2) Delivery delay

Delivery delay performance is shown in Fig. 8. The figure shows the cumulative frequency distribution corresponding to delivery delay. For example, the ratio of packet reaching to their destination within 300 seconds accounts for 90% of the total number of generated packets for our proposal. ER has the best performance due to packet broadcasting. Within 200 seconds, 90% of generated packets have successfully arrived at the destination. However, for KNOF and Utility based schemes approximately only 65% of generated packets could reach to their destination successfully within the criteria of 300 seconds. The graph of our proposal lies between ER and these two single-copy schemes, and it is even closer to ER. About 90% of generated packets can satisfy the criteria in our proposal.

(3) Influence of car traffic on performance

Figure 9(a) shows how delivery rate changes in accordance with the amount of car traffic. With increase of car traffic, in principle transient MANETs are more frequently and easier formed among nodes during routing process, which causes the improvement of delivery rate. When compared to the existing schemes, the proposal has better performance than KNOF and Utility based schemes and even similar performance to ER for the case of heavy traffic. It can be said from Fig. 9(b) that network resource consumption of the proposal is the smallest among all, even considered around 2.1% of the simulation error obtained. The reason for this is that these existing single-copy schemes have inherently difficulty to find appropriate next forwarding node and then their forwarding processes incline to be wasteful and meaningless, while our proposal can choose more efficiently next forwarding nodes towards the destination. More details on network consumption are depicted in Fig. 10 for the traffic of 40 cars per minute. It shows the number of packets which are categorized into segment group of the total number of radio transmissions for delivery success, which is equivalent to network resource consumption. In our proposal, there is a high peak at the small number of radio transmissions, i.e. from 9 to 21. The proposal can succeed to carry packets to the goal with smaller network resource usage.

4.2.4 Analysis of the Proposal

In this section, detailed results for our proposal are shown and its performance is discussed.

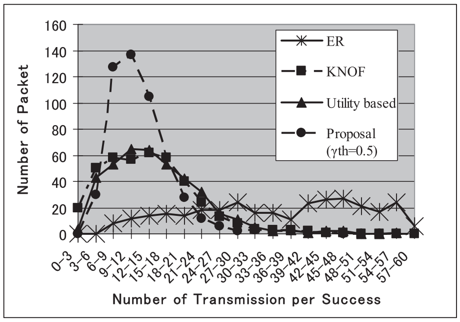


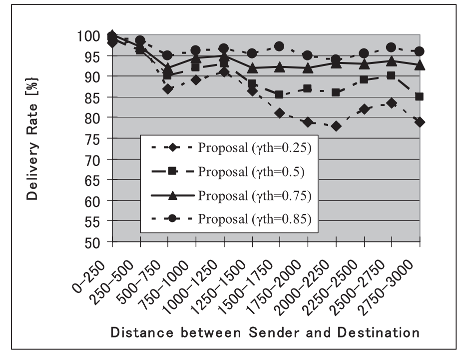
Fig. 10 Network resource consumption. (car traffic = 40 cars/minute)

(1) Performance by approach ratio (γ)

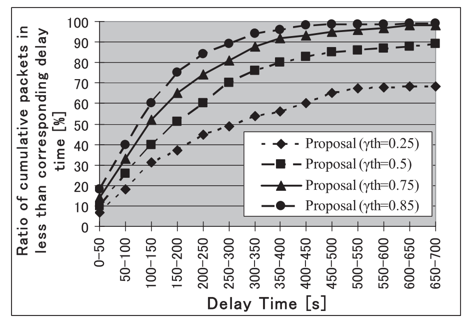
Figure 11 shows the influence by the approach ratio threshold γth on the performance for low traffic condition of 10 cars per minute. In Fig. 11(a), with increase of γth, the delivery rate of the proposal approaches toward 100%. The proposal characteristics in principle shall approaches to that of single-copy scheme when γth is smaller, while it approaches to that of ER when γth is larger. In Fig. 11(a), the trend of decrease to the distance, that is not monotonously though, appears according to the value γth being smaller, especially remarkable for γth = 0.5 and 0.25. It is likely that the characteristics of single-copy become to account for the performance trend even though the performance is improved as a whole. In our conditions, with γth more than 0.5, multi-copy effect becomes predominant. As we already observed in Fig. 7(a), single-copy schemes suffer still the impact of the traffic pattern and road layout. Then it can be estimated also that at the distance of around 1000–1250 m and 2500–2750 m, the distribution of the intermediate nodes to the destination becomes dense to be better inter-networked, especially for γth = 0.5 and 0.25.

In Fig. 11(b), it shows similarly to Fig. 8 how much percentage of the packets among the total success number of packet reach within certain delay time for each given γth value. The ratio of the number of packets with less 300 seconds delay time is smaller by about 10% compared to that of Fig. 8 with larger car traffic 40 cars/minute for γth = 0.75. Therefore, the delivery delay does not get satisfied the target criteria of 300 seconds very well in case of lower car traffic and lower γth value. In a realistic scenario being considered, road congestion information shall be requested to be updated more frequently in the area of higher car traffic for the higher probability of congestion than in the area of lower car traffic. Then we consider that the obtained performance trend is acceptable for lower traffic condition. The criteria in itself such as delivery rate and delay time is relative depending on traffic conditions of countries, regions etc. Therefore, if taken those results and trend into account, the approach ratio has to be manged. That is to say, we will have to rearrange the approach ratio and its definition using movement history information when the criteria are changed.

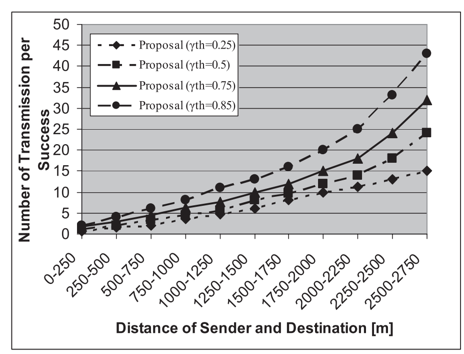
In Fig. 11(c), as expected, the network resource consumption increases with larger values of γth. At the distance



(a) Delivery rate



(b) Delivery delay



(c) Network resource consumption

Fig. 11 Effect of approach ratio threshold γth. (car traffic = 10 cars/minute)

of 2500–2750 m, it consumes more than twice of network resource for γth = 0.85 compared for γth = 0.25 because of large redundant transmissions in total.

From these results, we can conclude that γth is a key parameter that can determine and adjust the behavior of the proposal between multi-copy and single-copy schemes and it balances the tradeoff between performance and overhead. The approach ratio considering movement history plays significantly important role to filter valuable multi-copy nodes for efficient forwarding. The large value of γth can generate in wider range more greedy nodes which participate in SCF operation.

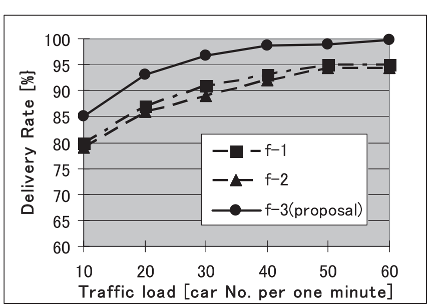
Namely, the delivery ratio and delivery delay improve with larger value of γth while the network resource consumption deteriorates. From a practical point of view, when the system (traffic center) covers a large area with low car density, a large value should be set for γth in order to obtain higher delivery rate and shorter delay. Even though such strategy leads to higher network resource consumption, one can use more network resource with low density of nodes and it can redeem the drawback. On the other hand, when the system covers a small area with high car density, a small γth value should be set in order to save network resources. In that case, the delivery rate and delivery delay are still anticipated high for high car density.

In some cases, the broadcast storm might occur when many of the passive nodes could become active at the certain point in case of, for example, high way scenario in congestion. To mitigate or avoid this, there could be some other solutions required. For example, according to the level of car density, the approach ratio can be changed dynamically in a way that the storm area would be limited. Another solution would be that only limited number of active nodes forward packets to the nodes which don't have those packets ever. Further investigation on the issue would be required.

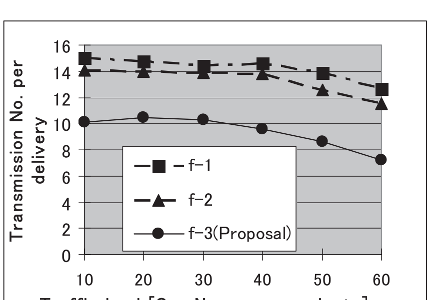
(2) Comparison of selection method

In this section, we apply our proposal, the passive-active transition scheme utilizing the parameter "approach ratio", to the other single-copy schemes in order to observe the effect of our proposal. The single-copy schemes are different in their selection of the next forwarding node. We combined the transition scheme with the function of KNOF defined as Eq. (7), which is called f-1 hereafter, and the function of Utility based scheme defined as Eq. (8), which is called f-2. Our proposal is denoted as f-3.

The results are shown in Fig. 12. When comparing the existing functions of selection, it is likely that our proposed function f-3, which takes into account several geographical parameters that prescribes a node motion such as position and velocity of node Eq. (2), provides slightly stable and high delivery rate for different traffic load comparing the functions of Eqs. (7) and (8). The enhancement of approximately 6% at maximum is gained for traffic load of 30 cars per minute in comparison with f-1 and f-2. Concerning network resource consumption it is the smallest for our proposal by a factor of 4 or 5, i.e. about 30% reduction, with respect to the others. Hence, with consideration of geographical aspects as above, the greediness toward the destination can be improved.



(a) Delivery rate



(c) Network consumption

Fig. 12 Effect of passive node concept. (γth=0.75)

When compared with Fig. 9, the delivery rate improves as a whole while the network resource consumption does not change so much. The results also show that the existing methods can reach our target performance of 80% for varied traffic, and the proposal is major part in vehicular DTN system. The difference of performance verifies the proposal's effect that the delivery rate can be improved around 5–9% while network consumption is still kept as low as the single-copy schemes. It suggests that the effect of the improvement by the proposed "approach ratio" is higher than that of the difference of selection function. In other words, even only introduction of the approach ratio has pretty good impact on the performance to be able to apply to other forwarding selection methods independently.

This is rather preliminary comparison and selection function itself needs to be studied further for each movement model and scenario. It is, nevertheless, indicated that considering movement history and encounter statistics leads to further improvement.

5. Conclusion

In this paper, we have proposed a new DTN scheme to obtain higher delivery rate and lower delivery delay while keeping or suppressing the increase of wireless network resource consumption. Our proposal gives priority to network resource consumption. We based our proposal on single-copy type DTN scheme (S-SCF) that is capable of economic usage of the resource and introduced the movement history by the parameter "approach ratio", where nodes located in the proximity of one hop area from a relaying node hear, copy, keep a broadcast packet and then becomes passive nodes. A passive node becomes an active node when it comes closer to the destination beyond the pre-determined approach ratio threshold (γth). The approach ratio defined as movement history allows the proposal to supplement S-SCF with property of multi-copy scheme that generates capability of valuable multi copy forwarders for the purpose of gaining higher delivery rate. In addition, by selecting the next forwarding node, the parameters such as position, velocity and direction that specify node mobility are considered to sharpen greediness toward the destination in our proposal.

Through simulation evaluation, our proposal is compared to three typical existing schemes with respect to network resource consumption, delivery rate, and delivery delay. The proposal shows the best performance regarding the targeted performance criteria. It is also verified that by adjusting approach ratio threshold (γth), we can balance the tradeoff between performance and overhead. Moreover, it is also suggested that the approach ratio can be independently introduced to other methods.

Important work still remains. First, we need investigation of the impact of the approach ratio threshold in accordance with system condition and application requirements. Second, we need a mechanism to inform other nodes of delivery of packet to the destination to let them discard copies of the packet. Otherwise useless packets would still hover in the network system, and network resources and memory capacity will be wasted. Third, we need to implement the proposal into actual nodes to verify its practicality and applicability. Lastly, in reality radio range is dynamic in time and location depending on the environments. We plan to evaluate the performance for varied range in order to obtain the impact.

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