Routing Metric based on Slot Length of AODV on Multihop DESYNC-TDMA

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ABSTRACT
DESYNC-TDMA is a representative bio-inspired MAC protocol which assigns slots of each node evenly in decentralized manner. However, it could suffer from bottleneck node on the delivery path because the slot is evenly assigned according to the number of neighbors in two hop range. In such a case the routing path having smaller slot length could be chosen due to its shorter hop count. This problem causes performance degradation. In this paper, we propose a routing metric using both slot length and hop count with cross-layer approach. Our scheme improves overall network performance by choosing and updating better route.

Categories and Subject Descriptors
C.2.1 [**Computer Communication Networks**]: Network Architecture and Design – *Distributed networks*

General Terms
Algorithm, Design, Performance

Keywords
Desynchronization, Self-organizing, Slot length routing, MANET, Medium Access Control, D-TDMA, Cross-layer

1. INTRODUCTION
Mobile ad hoc networks (MANETs) will play a significant role in communication networks without the help of fixed infrastructure, which require self-organizing, self-maintaining, and self-healing capabilities even while nodes are moving. It is expected that numerous number of nodes are distributed and involved in communications in MANET environments.

In such MANET environment, resource sharing among nodes mostly has been studied by contention based MAC protocol such as IEEE 802.11 DCF [1]. However, the DCF uses lots of bandwidth to avoid collisions, thus it is not suitable to reliable transmission of critical flows due to its uncertainty. Recently, to overcome these problems, Dynamic TDMA protocols are arisen. Every node in D-TDMA can be assigned by decentralized and distributed manner.

DESYNC-TDMA [2] is categorized as a D-TDMA scheme and truly inspired by synecology of firefly, i.e. inverse of Firefly Synchronization [3]. Reference [4] showed the DESYNC-TDMA and Firefly algorithm are based on PCO mechanism which node's state affects other's state in the next step. DESYNC-TDMA distributes fires of each node evenly in cycle and is very simple to implement.

However, MAC protocols based on DESYNC should share the bandwidth evenly among *n* adjacent nodes regardless of how much data to send each node has. If a node in delivery path has lots of neighbors, then the length of assigned slot is too small and cannot guarantee the enough bandwidth. In such a case, it is severe in the multihop environment which crosses several traffic flows.

In AODV routing protocol, the fastest request that reaches to the destination will be responded as a shortest route i.e. usually minimum-hop-distanced route. In DESYNC scenario, such a minimum hop route could have small amount of bandwidth due to its large number of neighbors. Then the shortest path using minimum hop causes less throughput and more delay because of less trunk capacity.

Several researches to overcome this bottleneck scenario in wireless network exist. Yielding slot to the neighbors in DESYNC [5] is proposed, but it is limited to the MAC protocol and it cannot choose better route than hop based shortest path scheme only by using the yielding scheme. Some routing metrics using path bandwidth or path capacity on CSMA MAC protocol are proposed [6][7][8] with cross-layer concept. Especially, [6] proposed to exploit the assigned slot length of node in TDMA network to routing protocol, but its calculation is somewhat complex.

In this paper, we exploit the slot length of each node in DESYNC-TDMA to calculate the routing metric combining with conventional hop distance. To achieve this, the route request carries minimum bandwidth (which can be interpreted to the capacity of delivery path) and the destination node replies the best cost route among several requests. We can choose a route that has the minimum cost of product of inverse of slot length and inverse of hops as the best route. With our metric AODV can choose better route that can forward more traffic and can improve overall network performance.

The rest of this paper is organized as follows. Section 2 briefly describes DESYNC-TDMA and its multihop extension, the cross-layer approaches in TDMA network, and overview of AODV routing protocol. Then, we describe the proposing routing metric on DESYNC-TDMA in section 3 and the experimental result will be given in section 4. Finally, Section 5 concludes the paper.

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2. BACKGROUNDS

2.1 DESYNC and its Multihop Extension

2.1.1 DESYNC-TDMA [2]

DESYNC-TDMA was proposed for sensor network to secure their own slot by distributed manner. It was inspired by firefly but the nodes evenly distribute their fire in the cycle. (i.e., it does not try to synchronize its fire at a certain point.) DESYNC-TDMA uses Pulse Coupled Oscillator (PCO) to adjust firing time of each node, described in Figure 1. Every node fires at their own firing time which is calculated by each node using the information of firing of previous and next node. According to the rule of DESYNC-TDMA, every node in next cycle fires at midpoint between firing time of previous firing node and next firing node in the current cycle. Each node can use its assigned slot in the next cycle, which starts the midpoint of previous node's firing time and its firing time, and ends the midpoint of its firing time and the next node's firing time.

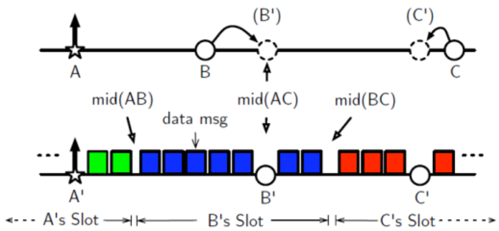


Figure 1. Adjusting its fire and assigning slot in the DESYNC-TDMA [2].

Each node using DESYNC-TDMA have a totally non-overlapping slot. For example, in Figure 1 the node A's slot ends at the midpoint of A's fire and B's fire, denoted mid(AB). With the same way, the node B's slot starts at the midpoint of A's fire and B's fire, which is the same as the end time of A's slot and non-overlapped. Note that, the scheduling slot start, slot end, and next fire time at each node occurs when receiving a fire message from other node just after its fire. The equations for these calculations are follows:

$$slot_{start} = T + (fire_{prev} + fire_{my})/2\ , \tag{1}$$

$$slot_{end} = T + (fire_{my} + fire_{next})/2\ , \tag{2}$$

$$fire_{my\_goal} = T + (1-\alpha)\times fire_{my} + \alpha \times (fire_{prev} + fire_{next})/2 \tag{3}$$

where $\alpha \in (0,1)$ is the jump-size parameter for EWMA and T is the cycle length and those equations are quoted from pseudo code in [2]. Note that they mentioned α must be much smaller in order to achieve convergence because the forwarded fire requires more time to propagate.

2.1.2 Multihop extension [10] for DESYNC-TDMA

The authors of DESYNC [2] discussed the multihop constraint in [9] which is their successive paper. Briefly, the nodes within 2-hop distance range should not use overlapped slot simultaneously. They also analyzed several topologies and showed the convergence and safeness if the nodes use slots with wireless constraint topology.

The detailed firing process to exchange the information of 2-hop neighbors was proposed in [10]. A node forwards neighbors' fire via its fire. The fire message has unique identifier of the node and the list of 1-hop neighbor's fire information such as ID and *delta* phase.

If node *i* receives a fire message from neighbor *j*, which is directly connected to node *i*, the node *i* removes node *j* from 2-hop neighbor list (N_2) and adds it to 1-hop neighbor list (N_1) if node *j* is not included in N_1 of node *i*, because node *j* is directly connected to the node *i*. Node *k*, which is one of neighbors carried by the fire message from node *j* should be inserted in N_2 if $k \neq i$. Note that the firing phases (*delta*) of all neighbors in fire message should be updated. Through this exchanging process, every node has a map of firing about adjacency (previous and next) nodes and finally the node *i* assigns non-overlapping slot within the 2-hop distanced neighbor's slot.

2.2 Relief Slot Length Problem on Bottleneck

Our previous work [5] is that a node yields its slot to previous node and next node if it has unused slot. Nodes in firing notify its remaining slots in the fire message and that amount of slot can be used by the adjacent nodes.

Such a yielding slot process is performed by all nodes in the network and affects slots of the previous and next node of each node. However, the fire phase of each node is not affected and not movable by this yielding process. Thus there is a limitation of securing slot if a node has excessive data to send than its slot assignment. In addition, this yielding scheme is not related to the routing decision, although it secures more bandwidth at the bottleneck point.

2.3 Routing Protocols using Slot Length

There are some studies on routing metric using slot length on delivery path. First, [6] introduced "path bandwidth" which is minimum bandwidth based on number of slots on the delivery path. The routing protocol they proposed chooses a first route which satisfies the QoS requirement of the flow, and it drops requests not satisfying the bandwidth. The path bandwidth is based on the TDMA protocol, and its bandwidth is obtained by:

$$BW(P) = \min_i \left| TS_i^P \right|, n_i \in P \cap \overline{n_0} \tag{4}$$

where transmission schedule TS at node *i* for path *P*, and n_0 is the destination. The transmission schedule includes transmission slots and receiving slots which are performed safely. This protocol can build a route satisfies the QoS level from a source to destination by reserving bandwidth. The bandwidth calculation is done hop-by-hop.

Reference [7] is based on IEEE 802.11 environment and it chooses the highest value of Bandwidth Distance Product (*BDiP*). They gave only the metric *BDiP* as follows:

$$BDiP = r_d \times d_h \tag{5}$$

where r_d and d_h stand for achievable data rate and distance (in meter or hop count) for each hop, respectively.

Reference [8] is a successive result of [7], and it showed routing protocol could choose a farther route with better metric. It also extended the *BDiP* to path bandwidth in [6], called "path capacity." The path capacity refers maximum end-to-end throughput, and the capacity can be used for admission control of the excessive flow. It rebroadcasts the route request if the metric carried by the request is better than the one it already has. However, these routing metrics of [7] and [8] are not based on the TDMA and their calculation is somewhat complex. Thus the simpler routing metric for the DESYNC protocol which assigns its slot in decentralized manner is needed.

2.4 AODV Overview [11]

In this section, we describes route setup process of AODV routing protocol briefly in point of view of route selection. AODV is a representative reactive routing protocol in MANET that forwards route request to the network after receiving data if there is no route to the destination of it. AODV uses next-hop routing scheme and determines the best route with hop count as a metric based on distance vector. We choose AODV routing as a target for improvement since its route discovery mechanism is very simple and relies on a dynamic metric calculated by information carried by control packets.

Route Request (RREQ) carries hop count from originator of the request, and every node can know the distance to the originator. The important criterion is the fastest request will be chosen as a route to respond. The route having the shortest hops to the destination is mostly chosen because the request will reach faster than others even though it has smaller amount of slot length in delivery path. Other late requests are discarded if the sequence is the same as the one of prior request. Therefore, the route having more capacity can help improve the network performance and it is needed for the destination node using AODV to choose better route to be able to forward its data from originator.

3. ROUTING METRIC USING SLOT LENGTH

3.1 System Model and Routing Metric

There are many attempts to use a value from running situation on MAC protocol for route decision. Routing metrics should reflect the slot length which can be used to the transmission on the MAC layer, especially in the TDMA-based MAC protocol. Figure 2 is an example for problem definition, which shows a comparison to the slot length and hop count in three different delivery paths.

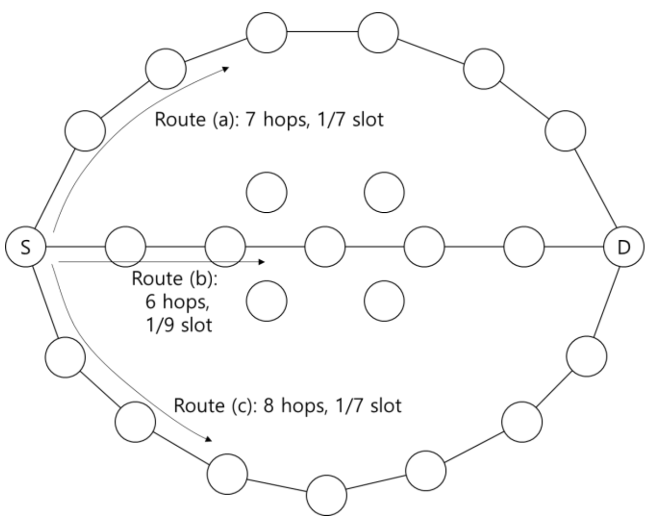


Figure 2. (Problem definition) comparison to the slot length and hop count.

Route (b) has shortest hop path with smaller capacity whereas (a) and (c) have longer hop path with larger capacity on the delivery path. AODV [11] usually uses route (b) but its capacity is lower and its end-to-end delay performance should be poor due to the bottleneck. Thus we propose a metric combining slot length and hop count together. We propose this metric on AODV protocol but it is not limited to the routing protocol.

3.2 Routing Metric (Cost)

Slot length is a basic parameter of TDMA-based MAC protocols. It is assigned to the node by its necessity, and the length can be varied by demand or purpose. In DESYNC-based MAC protocols, the slot length is determined by its neighbors in two hop range since the transmission of each node should not be overlapped, called hidden node problem.

Slot length is basically time (second) and is determined evenly in desynchronized phase according to the number of neighbors. Thus all the nodes in the delivery path does not have the same length of slot and the slot is assigned from the half of the previous node’s fire and my fire to the half of my fire and the next node’s fire, as shown in Figure 1. Thus, no node can estimate the number of neighbors, only the time will be carried to the destination.

Hop count is a traditional metric to determine the best route to the destination in routing protocols. To collaborate with slot length and hop count we need to adjust the effect of hop count to the metric due to scale difference of those. We use the hop count as inverse of hop count, and the final equation of the metric (cost function) is written by:

$$c_i = t_{slot\_min,i} \times \frac{1}{h_i} \tag{6}$$

where c_i is the cost function from neighbor i, $t_{slot\_min,i}$ is a minimum slot length of the path, and the h_i stands for hop count. With inverse of hop count, we can have semi-linear cost function which has better value if it has less hop and longer slot length.

3.3 Modified AODV for Applying Slot Length

To applying the cost function to the AODV routing, we modify the forwarding policy of route setup process in AODV. Several Route Request (RREQ) can be received at a node due to multiple links in MANET environment. Basically, AODV discards successive RREQ having the same sequence even if it has less hop count. In our case, the successive RREQ having better cost than the first will be discarded, thus the overall network performance will be degraded.

In this paper, every node rebroadcasts the RREQ if the carried cost is better than the previous value in the route table entry (RTE) after update the cost in the RTE, when an intermediate or the destination node have a RREQ having the same sequence. It causes forwarding redundant request messages that having the same originator and destination, but it will work as a new route having better cost.

4. EXPERIMENTAL RESULTS

To show our scheme make better choice, we simulate using Riverbed Modeler (formerly OPNET Modeler). We used the extended DESYNC [10] algorithm as a MAC protocol which is multihop extension of DESYNC-TDMA. Then, we modified the basic AODV protocol and the slot length information obtained from MAC protocol as a cross-layer concept when the RREQ is forwarded.

We configured a simple topology as shown in Figure 2. The data rate of network was set to 1Mbps, and each node has 256kbit of MAC buffer. The traffic is generated with the interval of exponential (0.008 sec) distribution and 2240 bits/packet, on originator. There are three routes from originator to destination, and their cost is little bit varied.

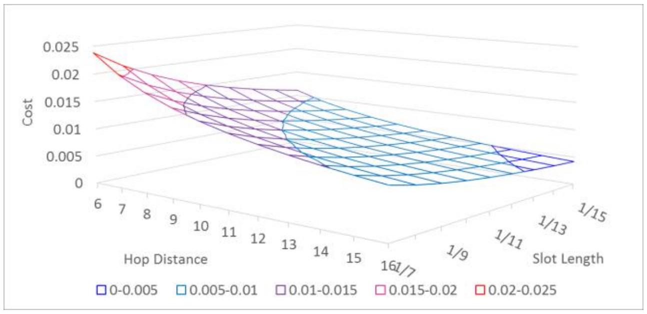


Figure 3. Cost varying the slot length and hop distance.

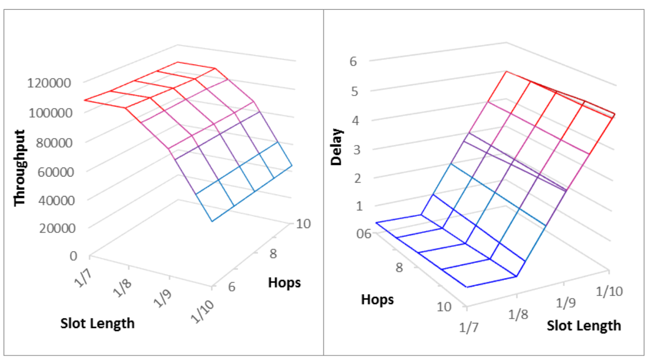
Figure 3 shows the value of cost function varying the slot length and hop distance. The cost decreases as inverse of hop distance and slot length decrease. It means shorter distance and longer slot are reflected to cost well.

Table 1. Cost comparison of the example paths in Figure 2

Route #	(a)	(b)	(c)
Hops	7	6	8
Min. Slot Length (sec)	0.016656	0.010949	0.016658
Cost	0.002379	0.001824	0.002082
EtE Throughput (bps)	107,829	60,005	107,025
EtE Delay (sec)	0.30612	295.7915	0.33633

Table 1 shows the initial result of calculation using equation (6) and its performance. The underlined values are the best among those. The route (b) has the shortest hop but their throughput is much poor as we expected. Their delay performance cannot be usable due to its queuing delay in bottleneck point. Route (a) is better than (c) which has different hop distance.

There are variations of end to end throughput and delay according to the hops and slot length, depicted in Figure 4. It shows the impact of slot length is bigger than that of hops.



(a) Throughput (b) Delay

Figure 4. Throughputs and delays varying the slot length and hop distance.

5. CONCLUSION

We proposed a routing metric using both hop distance and slot length of DESYNC-TDMA together with cross-layer approach. The metric we applied for routing protocol is calculated by the product of inverse of hop distance and slot length. The metric chose a route with longer time slot and shorter hops than the original AODV selected. With our metric the overall performance can be improved, and the advanced admission control for tactical networks by using the metric will be studied in future.

6. ACKNOWLEDGMENTS

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