MANET Topology Control Based on theNode Degree and Energy Detection Threshold

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Abstract—**In a mobile ad hoc network (MANET) constructed of mobile terminals, instability of communication and energy consumption are often a problem. Topology control of the network by transmission power has been investigated to stabilize the communication in a dense environment and to reduce energy consumption. However, the singly-linked nodes generated by topology control may cause the routing packets to collide. Therefore, in this study, we propose a new topology control that maintains the doubly-linked nodes by controlling not only the transmission power but also the threshold of energy detection based on the number of adjacent nodes (node degree). In addition, in order to minimize electric wave interference and the time required to control the topology, the proposed method controls the average degree to within a range, rather than to a single point. Our topology control suppresses electric wave interference, stabilizes communication, and conserves electrical power in the nodes. Simulation under mobile environments revealed that the proposed method increases the packet delivery ratio and decreases power consumption.**

Keyword—MANET; Power saving; Transmission power control; Topology control; Node degree; Energy detection threshold

I. INTRODUCTION

Along with the current development of wireless technology, autonomous distributed networks or mobile ad hoc networks (MANETs), which do not require a base station (base-station free), have been gaining attention. MANETs are expected to be used in various fields, such as for areas where it is difficult to use cables, during disasters, and to secure communications in Internet technology services (ITS). However, since the topology of the mobile network changes frequently, such networks are not stable, which decreases the rate of delivery. Since the wireless mobile terminal (node) plays the role of both relay device and end system, a large amount of power is consumed for routing. This becomes a problem, as wireless mobile terminals rely on a battery to power on.

MANET research has therefore prioritized the goal of stabilizing the network and conserving power. Kawamura et al. [1] attempted to save power in routing by using the Expanding Ring Search method. Expanding Ring Search was used to prevent the increase of RREQ messages from flooding from the starting node when searching for a route in an Ad hoc On-demand Distance Vector (AODV) [2, 3] network. While AODV's Time to Live (TTL) uses the number of hops as a reference, Kawamura used the load of the node and remaining battery level as the reference values by the Expanding Ring Search to reduce the overhead of search and save power. However, when the nodes are overcrowded, a large number of packets are generated, and it is difficult to deal with them by using the routing method alone.

Therefore, to conserve energy, attempts have been made to control the topology by controlling the transmission power, which is called the topology control method. When mobile nodes are overcrowded, each node decreases the transmission power to reduce the number of adjacent nodes (node degree). Thus the routing in the network is stabilized and each node's power consumption is reduced [4, 5]. In fact, when controlling the transmission power, a phenomenon called singly-linked nodes occurs. As a result, hidden terminals are increased and packet collisions occur more frequently, disrupting communication.

A routing protocol that uses singly-linked nodes has been proposed [6,7]. When searching for a communication route, the flooding area is controlled adaptively using singly-linked nodes to enhance connection among nodes. However, since control packets are flooded when backward searching, the total overhead of the route-search is larger than that of the existing routing method when all nodes have the same power or are doubly-linked.

Fukui et al. [8] proposed a routing protocol to construct a route avoiding singly-linked nodes to reduce packet loss. They also propose a routing protocol that predicts the singly-linked nodes by guessing the movement of the nodes using the Hello message and location information [9] to avoid them. However, it is unclear whether either of these methods is effective at saving power.

As an alternative approach, sleep nodes that perform independently using random probability control in an asynchronous network have been introduced [10]. In this case, singly-linked node problems cannot occur, since the nodes sleep. The power saving is thus highly effective. However, because of the probability control, there is a risk that a node will not be able to receive packets when asleep.

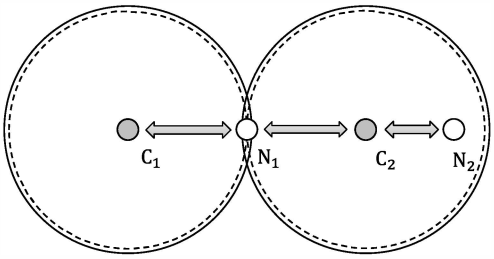
In the previous study, the authors tried to control not only the transmission but also the receiver power of the relay nodes to solve the singly-linked problem [11]. As a result, it is found that the packet delivery ratio improves and each node's electric power is conserved. Nonetheless, the authors left the question of the optimum degree during power control for a future investigation.

Therefore, here, we propose an optimum degree-based method of topology control by controlling the energy detection threshold so that singly-linked nodes do not occur.

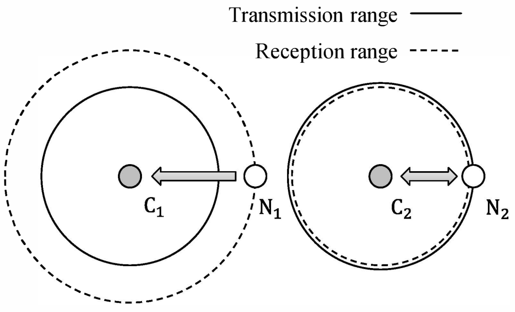
II. PROPOSED METHOD

A. Topology control by power control

Because high-transmission power of wireless nodes causes radio waves to propagate a long distance, radio interference occurs over a significantly wide range. Therefore, the general goal of topology control is to prevent radio interference by lowering the transmission power [12,13]. However, the communication between nodes is determined not only by the transmission power of the sender node, but also by the power detection threshold of the receiving node.



(a) Uncontrolled state



(b) Controlled state

Fig.1 Topology Control with Transmission Power and Energy Detection Threshold Control

Figure 1 shows the pattern of transmission and reception among the four nodes. The transmission ranges of C_1 and C_2 are shown by solid lines, and their reception ranges are represented by dotted lines. C_1 and C_2 can send to the nodes in their transmission range, and can receive radio waves in their reception range. Figure 1(a) shows that the transmission power and wave detection are equal for each node. C_1-N_1, N_1-N_2, and C_2-N_2 can send and receive to each other. In Figure 1(b), the transmission power of C_1 is reduced. As a result, C_1 can receive radio waves from N_1, but cannot send them to N_1. This configuration thus includes singly-linked nodes. On the other hand, the receiving sensitivity of C_2 is reduced by raising the power detection threshold, while the transmission power of C_2 is reduced. Therefore, C_2 is no longer able to send or receive from N_1. However, because the distance between C_2 and N_2 is small, a bidirectional link is maintained between them, which can receive and send packets even if C_2 is controlled. In this manner, as for C_2, singly-linked nodes do not occur.

Therefore, in this study, the MANET topology is controlled based not only on the transmission power of each node, but also on its power detection threshold.

B. Control scheme

We propose the MANET topology control shown by Eq. (1). Here, P(t) is the transmission power at time t and P(t+Δt) is that after the power control at t+Δt. D(t) is the increment and $\Delta P_2(t)$ is the decrement in transmission power. We consider that there exists a range of node degree that allows smooth routing. D(t) should be controlled to be in the range between the target degrees Dmin and Dmax. These target degrees are determined by the simulation described in IV.A. The minimum transmission power Pmin[dBm] and the maximum transmission power Pmax[dBm] of each node depend on its terminal specification.

$$P(t+\Delta t) =$$
$$\min\{P(t)+\Delta P_1(t), Pmax\}\ (D(t) < Dmin)$$
$$P(t)\qquad (Dmin <= D(t) < = Dmax)$$
$$\max\{P(t)-\Delta P_2(t), Pmin\}\ (Dmax < D(t)) \quad (1)$$

$\Delta P_1(t)$ and $\Delta P_2(t)$ are given by Eq. (2) as the difference between the degree at t and the target degree. Here, α is a control factor.

$$\Delta P_1(t) = Pmax\ \alpha\ (Dmin - D(t))$$
$$\Delta P_2(t) = Pmax\ \alpha\ (D(t) - Dmax) \qquad (2)$$

In this study, the power detection threshold is controlled to eliminate singly-linked nodes generated by the transmission power control. Here, θ(t) is the power detection threshold at time t, and Pr,min is the minimum value of receivable power, θ(t) - Pr,min = Pmax - P(t). Thus, θ(t) is derived by Eq. (3).

$$\theta(t) = -P(t)+Pr{,}min + Pmax \qquad (3)$$

Since θ(t) => Pr,min and Pmin <= P(t) <= Pmax, the range of the power detection threshold for the control can be derived by Eq. (4).

$$Pr{,}min <= \theta(t) <= Pr{,}min + Pmax - Pmin \qquad (4)$$

III. SIMULATIONS

The transmission features of our proposed method were simulated using a network simulator, NS-3 [14] ver. 3.19. Table 1 shows the parameters used in the experiments.

TABLE 1 SIMULATION PARAMETERS

Parameters	Values
MANET routing protocol	AODV
Hello interval	1sec
Simulation time	100sec
Area size	$500m \times 500m$
Number of nodes	$10 - 150$nodes
MAC layer	IEEE 802.11b
Physical layer	IEEE 802.11b
Bandwidth	2Mbps
Packet size	64bytes
Traffic model	UDP
Data rate	4pps
Traffic nodes	20% of nodes

It was assumed that radio wave propagation took place in a space free from sources of isotropic implosion. The relationship between the power and the propagation distance was derived using the Log distance propagation loss model. In the simulation, source and destination nodes were selected first. All nodes broadcast Hello packets repeatedly at one-second intervals. The source node sent data packets at 2 Mbps to the destination node. The simulation was carried out 10 times for each condition, and the average data delivery rate (Ave. PDR), average energy consumption (Ave. EC), quantity of control packets (CP), and average delay (Ave. DLY) were measured.

Nodes in the mobile environment of our simulation were assumed to move based on a random walk model in two-dimensional space. The movement speed was assumed based on an average adult walking speed of about 1.5 m/s. Each node moved at about 1.5 *m/s* to a randomly specified destination $100m$ away. After arriving at the destination, it would then travel in another direction.

Before simulation, it was necessary to obtain the target degrees, Dmin and Dmax, of each node in the MANET. Dmin and Dmax were derived from the simulation results of the average of PDR and its standard deviation in a stationary environment with a random arraignment. Also, in order to determine α, changes of average node-degree with time were simulated with α = 0.001, 0.01, 0.1, and 1.0, and the value of α that gave the fastest convergence of the average degree with the smallest fluctuation was selected.

The simulations were performed using the above parameters. A flow chart of the power control used in this study is shown in Figure 2.

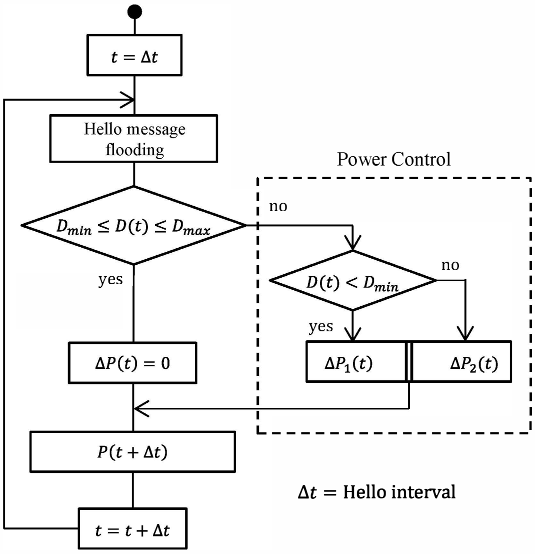


Fig. 2 Power control flow chart of the proposed method

In AODV, nodes send Hello message packets to hold the path entry 1 hop. So, in our proposed method, the electrical power of each node is controlled just before sending the Hello message in order to reflect the topology of the post-control in as close to real time as possible.

Moreover, the relation between the power values and current value is required in order to calculate the energy consumption. In this simulation, the data sheet of the RN-174 module [15] of a relatively low-power Roving Network is referred to as the power model.

TABLE 2 ENERGY CONSUMPTION OF AN RN-174, MEASURED AT 3.3V DV [15]

State	Idle	Rx	Tx[dBm]						
			0	2	4	6	8	10	12
Current[mA]	40	40	120	130	170	175	180	185	190

Current values are produced by Eq. (5), which was derived by applying a linear least squares method to the measured values in Table 2.

$$\mathrm{TxCurrent[mA]} = 5.893\ \mathrm{TxPower[dBm]} + 128.9$$

IV. SIMULATION RESULTS

The target degrees, Dmin and Dmax, and coefficient α are determined at the preliminary simulation, as described in A. The proposed method was then evaluated in a mobile environment using the parameters determined, where the number of nodes N was increased in steps of 10 units from 50 to 150, as described in B~D. The simulation results using the proposed method were compared to those using two other routing protocols. The first was an existing routing protocol AODV that does not control transmission power, and the second was AODV-TC, which controls the topology by transmission power control.

A. Target degrees

Transmission was simulated among 10-150 nodes arranged randomly to yield the average value Avg. and the standard deviation S.D. of the data delivery ratio (PDR). The results are shown in Figure 3. When the density of the nodes is appropriate, Avg. should be sufficiently high. Avg. exceeds 0.9 in the range of 30<=N<=90, as shown in Figure 3. Also, S.D. should be low for the network to be stable; S.D. drops below 0.1 in the range of 40<=N<=80 as shown in Figure 3. Therefore, the appropriate number of nodes was 40<=N<=80 in this simulation. The degree of each node can be calculated by counting one-hop entries in the routing table. The relationship between N and the average degree D is shown in Table 3. From Table 3, D is 7.35 at N=40, and 13.68 at N=80. Packet delivery becomes optimum when D is between 7.35 and 13.68. Thus, Dmin = 8, and Dmax = 13 were selected as the target degrees.

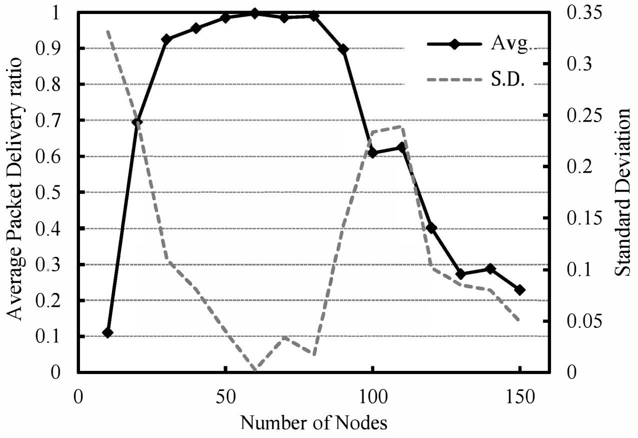


Fig. 3 Avg. and S.D. of the PDR

TABLE 3 NUMBER OF NODES VS. NODE DEGREE

N	20	40	60	80	100	120	140
Average Degree	3.72	7.35	10.04	13.68	17.22	20.21	23.74

The simulation was then complete in terms of finding the optimum value of the control coefficient. Figure 4 shows the changes in the average node degree D over time at N = 90 with variation of α. The average node degree can be seen to fluctuate when α = 1. Since the convergence speed is slow in the case of α = 0.001, the topology cannot be controlled quickly enough. When α = 0.1 or 0.01, it can be seen that the average node degree converges quickly and shows stability. However, for α = 0.1, the target degree falls at the first transmission stage. We thus chose α = 0.01 for this study.

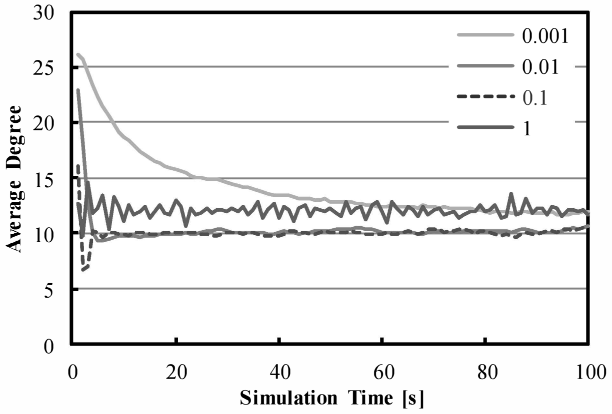


Fig. 4 Average degree in the simulation time.

Although in this study we proposed a range control using Dmin and Dmax, as shown in Eq. (1), we also simulated the transmission using Dmin, Dmax and Dave as the target degrees in order to compare the range-degree control and one-point control. Here, Dave was (Dmin+Dmax)/2. Simulation results at N = 90 are shown in Table 4. The results indicate that if the target degree is only one point, Ave. PDR is reduced, CP increased, and Ave. DLY more than doubled in all target values. Therefore, range control is preferable to one-point control.

TABLE 4 SIMULATION RESULTS BY TARGET DEGREE

	$\widetilde{PDR}$ [−]	$\widetilde{EC}$ [J]	CP [MB]	$\widetilde{DLY}$[ms]
$[D_{min}, D_{max}]$	0.86	16.42	6.20	82.85
D_{min}	0.65	16.69	12.47	385.74
D_{max}	0.79	16.41	8.14	231.62
D_{ave}	0.74	16.52	9.19	265.88

PDR~: Average Packet Delivery Ratio (Ave. PDR)
EC~: Average Energy Consumption (Ave. EC)
CP: Control Packets
DLY~: Average Delay (Ave. DLY)

B. Packet delivery ratio

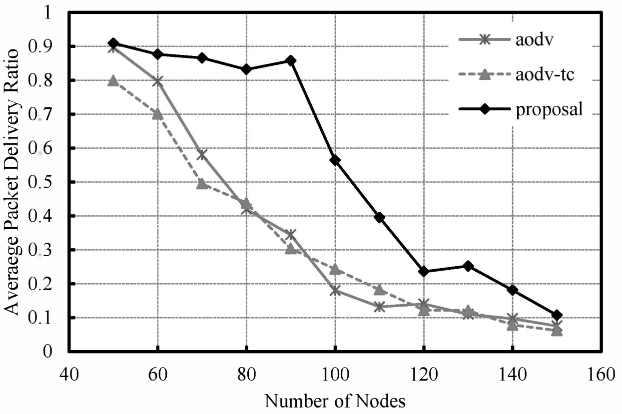


Fig. 5 Variation in Avg. PDR versus node number.

The average value of the data packet delivery ratio (Ave. PDR) was reduced as the number of nodes (N) increased, as shown in Figure 5. The fall in Ave. PDR was considered to be due to the congested state of the nodes, which would likely lead to radio interference and the loss of data packets through collisions. Routing packets are also lost by congestion, so that the constructed path is disrupted and the buffer of each node becomes full to the point of overflowing, which also induces data packet losses. The Ave. PDR of AODV-TC is reduced in the same manner as those of AODV. This is due to hidden terminal collisions under the influence of singly-linked nodes, even though radio interference can be suppressed by transmission power control. Although there is a similar tendency with the proposed method, unlike other methods it shows high PDR until N = 90, because it not only suppresses wave interference using the power transmission control method, but also suppresses the generation of singly-linked nodes by controlling the power energy detection threshold.

C. Control Packets

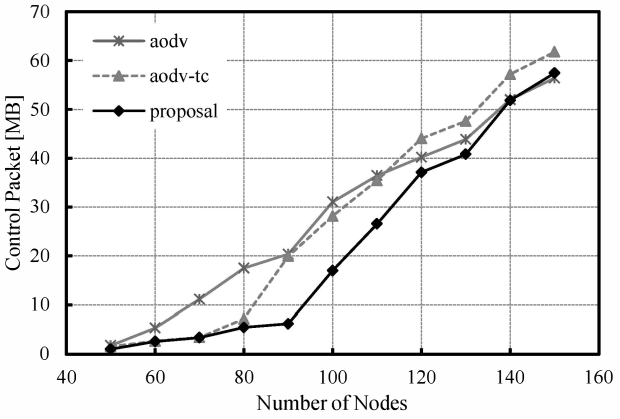


Fig. 6 Variation in CP versus node number.

Figure 6 shows the relationship between the number of nodes and the quantity of network-wide control packets (CP). As mentioned above, the number of control packets increases when the nodes are congested. When N>=90, AODV-TC creates almost the same quantity of control packets as those by AODV. With the proposed method, however, we can see CP is suppressed.

D. Energy consumption

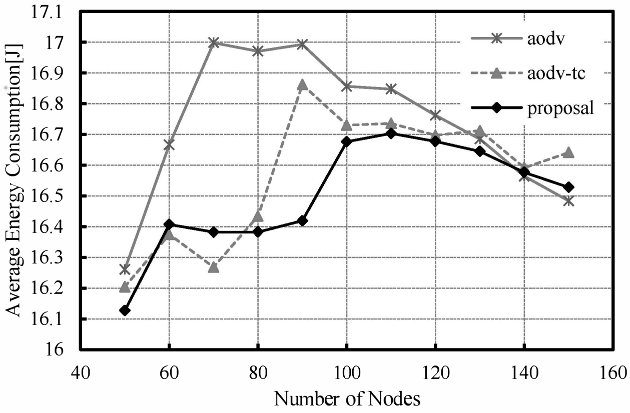


Fig.7 Variation in Avg. EC versus node number.

Figure 7 shows the average energy consumption (Avg. EC) at different numbers of nodes. Both the AODV-TC method and the proposed method use the AODV protocol. Ave. EC increases significantly at 90 < N < 100 for AODV-TC and the proposed method. This is because the routing reconstruction causes increase in control packets, and hence the increased energy consumption of each node. In addition, Ave. EC tends to decrease when N => 100. This can be seen in Figure 5, which shows that energy consumption decreases with the decrease in the data delivery rate.

E. Average delay time

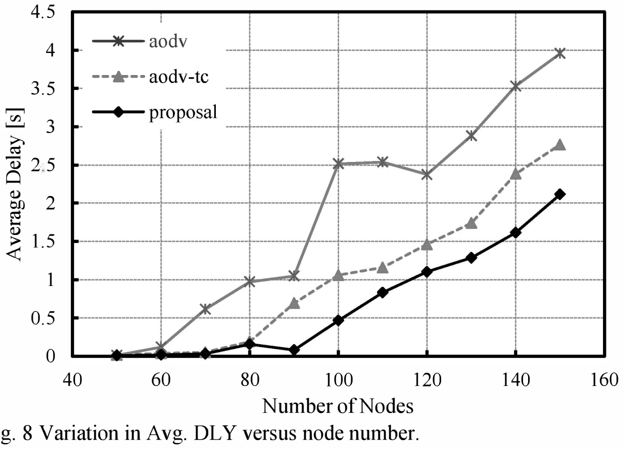


Fig. 8 Variation in Avg. DLY versus node number.

Figure 8 shows the average delay time (Ave. DLY) according to the number of nodes. The proposed method suppressed the delay to less than 100 *ms* until N = 90, which can be considered a sufficiently low value. When the degree is controlled by power control, the number of hops increases. Furthermore, when the route is reconstructed, the data packets must remain in the buffer of the source or relay node until the destination entry is established. This increases the delay in transmission. In our simulation using the proposed method, even though the hop counts increased, the delay was reduced because route reconstruction was decreased.

V. DISCUSSION

In the traditional topology control, the delivery rate is not particularly improved because that controlling only the transmission power leads to an increase in singly-linked nodes. Therefore, we propose to control the power detection threshold as well as the transmission power to reduce the profusion of singly-linked nodes and to improve both the power saving and packet delivery rate.

Although topology control aims to stabilize communication in an overcrowded mobile network, the rapid topology changes caused by topology control actually make communication unstable. In this study, we found that the optimal degree is a region rather than a single value. Therefore, we propose to minimize the topology change by controlling the nodes only to values within this region. In addition, no node will ever sleep in the proposed method. Therefore, it is possible for all nodes to participate in the network to maintain communication.

In the optimal degree region suggested in this study, transmission techniques of the datalink and/or physical layers such as reducing the radio wave inference or avoiding the collision of packets appear to achieve successful communication between nodes. Therefore, these techniques have the potential to widen the optimal region. α is a factor related to the rate of convergence, and thus it should be large as long as the communication does not become unstable due to violent fluctuation the radio wave range. However, the influence of the characteristics of ad-hoc nodes on these parameters is not clear yet. Further, the influence of the movement of the nodes on these parameters is also unknown. Thus, appropriate values and features of these parameters should be investigated in future studies.

VI. CONCLUSION

In this study, topology control in AODV was carried out by controlling both the transmission power and the power detection threshold. With the proposed method, the packet delivery ratio increased and power electric consumption decreased even in an overcrowded state.

In the future, to further prolong the survival of the network, not only the node degree but also the remaining energy of each node will be considered to control the power. In addition, the simulation be performed using map information and 3D coordinates.

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