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PERFORMANCE ANALYSES OF PATH RECOVERY ROUTING PROTOCOLS IN AD HOC NETWORKS

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ABSTRACT. On-demand routing protocol in ad hoc network is that establishes a route to a destination node only when it is required by a source node. But, it is necessary to reestablish a new route when an active route breaks down. The reconstruction process establishes another route by flooding messages from the source to the destination, cause not only heavy traffic but also long delays in route discovery. A good method for analyzing performance of protocols is important for deriving better systems. In this paper, we suggest the numerical formulas of a representative on-demand routing protocol AODV, ARMP, and RRAODV to estimate the performance of these routing protocols for analyzing the performance of these protocols. The proposed analytical models are very simple and straightforward. The results of analysis show good agreement with the results of computer simulations.

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1. Introduction

Ad hoc network is the cooperative engagement of a collection of mobile nodes without any centralized access point or existing infrastructure, where all nodes are capable of moving and can be connected dynamically in an arbitrary manner. Nodes in a network function as routers, which discover and maintain routes to other nodes in the network. The on-demand routing protocols establish a routing path to a destination node only when a source node has data to transmit[1-9]. AODV(Ad hoc On-demand Distance Vector routing)[4],

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DSR(Dynamic Source Routing)[5], TORA(Temporary-Ordered Routing Algorithm)[6], ABR(Associativity Based Routing)[7], SSA(Signal Stability-based Adaptive routing)[8] are categorized in this type. When a node requires a route to a destination, it initiates a route discovery procedure. This procedure is completed when a route is found or a possible route has been examined. If there is the route failure due to host mobility, signal interference or power outage, it requires additional time and overhead to reconfigure the route from the source to the destination. ARMP(Active Route Maintenance Protocol)[10] tries to prevent disconnecting of the current route by monitoring the status of the signal strength and the stability of the individual links. One node of a weak link performs a local route reestablishment process to find a substitute local path before the routing path is broken. If the local route reestablishment process fails, the route may be broken.

RRAODV(Robust Routing protocol of AODV)[11] increases the success probability of the local route reestablishment and enhance the route efficiency. In this paper, we suggest the numerical formulas of AODV, the representative on-demand routing protocol, and ARMP, RRAODV to estimate the performance of these routing protocols. The analytical models are very simple and straightforward. The results of analysis show good agreement with the results of computer simulation. The rest of this paper is organized as follows: section 2 presents overviews of routing protocols that avoid route breakage. Section 3 proposes the numerical formulas of AODV, ARMP, RRAODV. Section 4 presents the comparison of the simulation results. Section 5 has conclusions.

2. Local recovery methods of route

2.1. Ad hoc on-demand distance vector routing

AODV is an on-demand routing protocol and establishes a routing path to a destination node only when a source node has data to transmit. When the source node desires to send a message to the destination, it initiates a route discovery process. In fig. 1, source node S broadcasts a RREQ(Route Request) packet to its neighbors, which then forward the request to their neighbors, and so on, until either the destination or the intermediate node with a fresh enough route to the destination is received the request. Once the RREQ reaches the destination or an intermediate node with a fresh enough route, the node responds by unicasting a RREP(Route Reply) packet back to the neighbor from which it first received the RREQ. As the RREP is routed back along the reverse path, nodes along this path set up forward route entries in their routing tables which point to the node from which the RREP came[4].

If a source node loses the route to the destination, it reinitiates the route discovery protocol to find a new route to the destination. If a node loses the route by moving, there are two methods to repair the broken route. First, its upstream neighbor notices the move and propagates a link failure notification

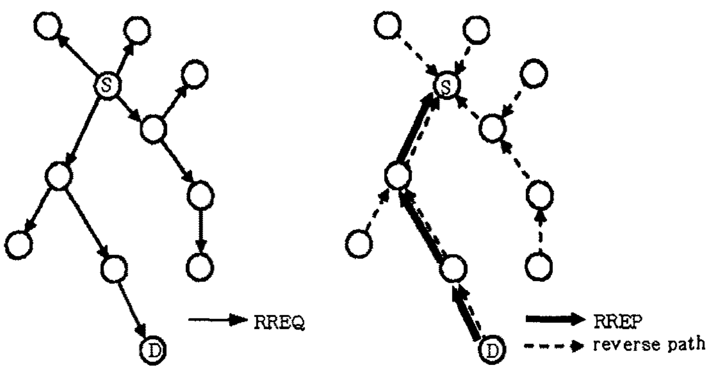


FIGURE 1. A route discovery process in AODV

message to its active upstream neighbors to inform a link failure. These nodes in turn propagate the link failure notification to their upstream neighbors, and so on until the source node gets the notification. The source node may then reinitiate route discovery for that destination. Second, the upstream node of the broken link may start to repair the link.

2.2. Active route maintenance protocol

ARMP establishes a substitute partial route before the occurrence of route disconnection[6]. When the state of a link is changed to be unstable, one node detects whether a route disconnection will be caused in the near future by the link status. One of two nodes of this link is selected as an active node to establish a substitute local path. ARMP mainly consists of two phases, ANDP(Active Node Determination Process) phase and LRRP(Local Route Reestablishing Process) phase. When the state of a link is changed from stable to unstable, one of the link nodes will be selected as the active node in the ANDP phase. Each node of the weak link transmits the variation of signal strength of its own neighbors and determines the active node by evaluating the variation of signal strength. In fig.2, the routing path is A, B, C, E, F. Node C moves and causes unstable link between node B and C at T_{i+1}. By measuring the signal strength, node B and C detects that link has become unstable and may break soon. Both node B and C will perform the ANDP to determine an active node. Node C identifies that it is an active node by evaluating the variation of signal strength.

The active node C then performs the LRRP process to repair the weak link. In the LRRP phase, a neighboring node will be selected to replace the active node so that the route can be stable state. The node selected in the LRRP should have a stable link state for the previous and the next node of the active node. In fig.2, the active node C sends an LRRP packet(previous node ID, next node ID, my ID, B, E, C) to all its neighbor nodes. When the neighbor node D receives the LRRP, it measure the link state to the previous node B and the

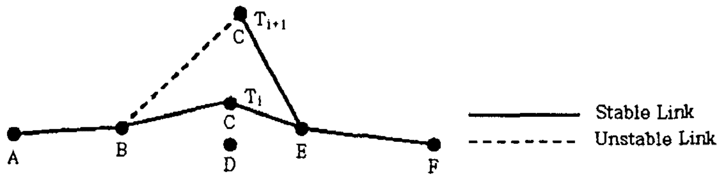


FIGURE 2. A local reestablishment process in ARMP

next node E and replies to active node C with the signal strength of these two links. When these two links are stable, the active node C determines node D as a substitute node. If the local route reestablishment process fails, the route might be broken.

2.3. Robust routing protocol of AODV

2.3.1. RRAODV for avoiding route breakage

The RRAODV extends the range of node selection and increases the success probability of the local route reestablishment[11]. Nodes on the routing path, active nodes, monitor the signal strengths to the next node on the routing path as the stability of the link state. When the signal strength of the link is less than SS_{thr}(Signal Strength threshold of stable link state), the link is considered to be unstable. If the link state is unstable, the reestablishment process is started to establish a substitute local path. The signal strengths of links on the ad hoc network are maintained in each node[8-11]. The reestablishment process has two steps.

First, the node which detect unstable link of downstream node selects one of the downstream nodes in its transmission range as a new next node. In fig. 3(a), the routing path has node S, A, B, C, E, F, G, D as active nodes on the route at T_i. In fig. 3(b), node E moves out and node C has a weak link connection with the next node E at T_{i+1}. Node C starts the reestablishment process to select a new next node. The downstream nodes of node C are nodes E, F, G, D. There is node F in the transmission range of node C at T_{i+1}. In fig. 3(c), node C selects the node F as the new next downstream node.

If there isn't any downstream node in the transmission range of node C, the reestablishment process migrates to the second step. In fig. 4(a), the routing path is S, A, B, C, E, F, G, D at T_i. Node C has a weak connection to the next node E at T_{i+1}. In fig. 4(b), there isn't any downstream node in the transmission range of node C at T_{i+1}. In this case, the first selection process fails. In the second step, the node C selects one of the non-active neighbors which have connection to one of the downstream nodes. The non-active node H is selected as the stepping node from node C to connect to the downstream node F. As the result, node H is selected as the new next node of node C.

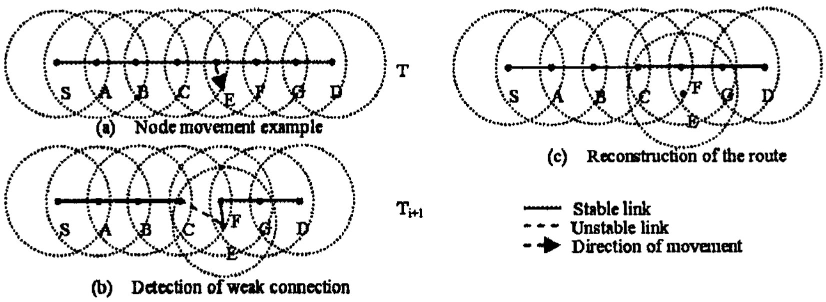


FIGURE 3. The selection of one of the downstream nodes as a next hop node

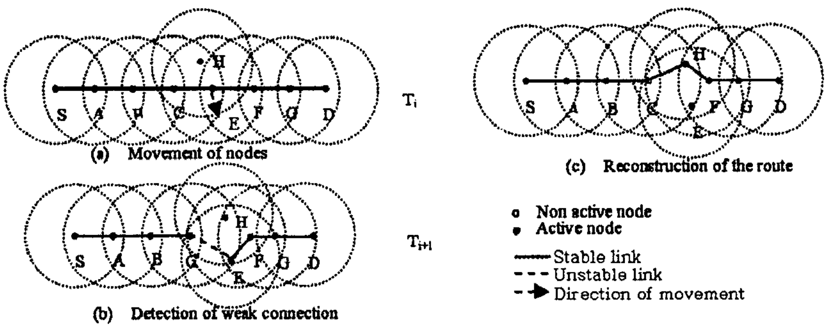
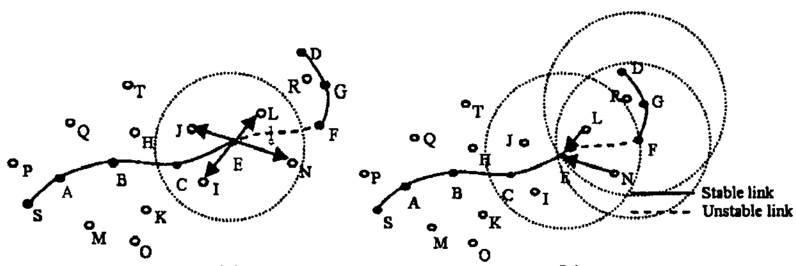


FIGURE 4. The selection of one of the non-route neighbors which have connection to the downstream node

2.3.2. Selection process for a new next node

The selection of a new next node has two steps. In the first local recovery process, when downstream nodes within it's own transmission range are available as a next hop node candidate, then the nearest node to the destination node have to be selected as the next node. If the process fails, the node broadcasts a SSRQ(Signal Strength Request) message to select a stable non-active node which will work as a stepping node to connect to one of the downstream nodes. In fig. 5(a), node E broadcasts a SSRQ packet, than one-hop-neighbor nodes I, J, L, N receive it. The SSRQ includes the information of the downstream nodes and the signal strength in fig. 6(a). The non-active nodes I, J, L, N check the information of the downstream nodes. If they have some information from the downstream nodes, they reply SSRP(Signal Strength Reply) packets including the signal strength information to node E. There is node L and N in the transmission range of the downstream node G and the next node F in fig. 5(b). Therefore, node L and N have managed the signal strength of node G and node F. When node L and N receive the SSRQ, they reply the SSRP to node E which includes the signal strength of nodes G and node F.



(a) SSRQ (b) SSRP

FIGURE 5. Gathering of the signal strength message

Type =5	Code =1	Reserved
Request node address = E		
Signal strength		
Next node address = F		
Signal strength		
1st downstream node address = G		
Signal strength		
2nd downstream node address = D		
Signal strength		

(a) SSRQ

Type =5	Code =2	Reserved
Request node address = E		
Signal strength = SS_{EL}		
Next node address = F		
Signal strength =SS_{GL}		
1st downstream node address = G		
Signal strength = SS_{GL}		
2nd downstream node address = D		

(b) SSRP

FIGURE 6. The format of the signal strength message

Node E selects one of non-active neighbors with a stable links to the downstream nodes on the routing path. The selected node must have the sufficient signal strengths to the previous node and the downstream node.

3. Numerical formulars for performance analysis

We propose numerical evaluation formulas which describe in AODV, ARMP and RRAODV. In fig.7, h_s(source hop count) is a hop count from the source node S to the current node E, h_d(destination hop count) is a hop count from the current node E to the destination node D, and h(hop count) is a hop count from the source node S to the destination node D. Hop counts before and after route breakage are marked using p(previous) and n(next). h_{sp} is h_s before route breakage, h_{dp} is h_d before route breakage, and h_p is h before route breakage. h_{sn} is a h_s after route breakage, h_{dn} is h_d after route breakage, and h_n is h after route breakage.

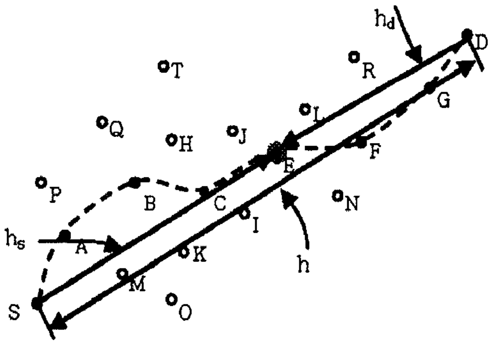


FIGURE 7. The hop count terminology

3.1. Route recovery of AODV

When a node loses the connection to the next node, it transmits a RERR message to the source node and the source node starts reestablishing process. T_{AODV} is the recovery time for AODV.

$T_{AODV} = \alpha(h_{sp} + 2h_n)$, where is a one-hop transmission time. (ms unit) (1)

In (1), h_{sp} is h_s before a re-route discovery process. It is the hop count that is required during the current node transmits a RERR to the source node. h_n is h after the re-route discovery process. $2h_n$ is the number of the hop counts that is required during the reestablishing process. It is the sum of the hop counts that is required during the source node broadcasts a RREQ to the destination node and the number of the hop counts that is required during the destination node transmits a RREP to the source node.

When a node tries a local repair, the node can broadcast a RREQ to the destination node. When the local repair process succeeds, the recovery time is shown in (2).

$$T_{AODV\_LRS(LocalRepairSuccess)} = 2\alpha_{dn}. \quad (2)$$

h_{dn} is the number of the hop counts from the current node to the destination node after a route brakeage. h_{dn} is the sum of the hop counts that is required during the current node broadcasts a RREQ to the destination node and the number of the hop counts that is required during the destination transmits a RREP to the current node in (2).

When the local repair process fails, the recovery time is shown in (3).

$$T_{AODV\_LRF(LocalRepairFail)} = \alpha(2(max(h_{dp}, 0.5h_{sp}) + k) + h_{sp} + 2h_n). \quad (3)$$

The RREQ that the current node has broadcast is discarded when the number of the hop counts is over than max(h_{dp}, $0.5h_{sp}$)+k in [4]. k is LOCAL_ADD_TTL and the default value of LOCAL_ADD_TTL is 2 in [4]. When the current node doesn't receive the RREP packet during a certain time, the local repairing process fails. 2(max(h_{dp}, 0.5 h_{sp})+k) in (3) is the waiting time of the RREP.

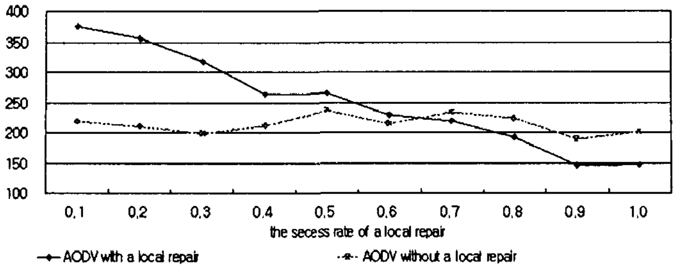


FIGURE 8. The recovery time in AODV with the local repair and in AODV without the local repair

TABLE 1. The success probability β of the local repair

Speed	Density								
	4	6	8	10	12	14	16	18	20
5m/s	0.365	0.485	0.655	0.710	0.725	0.785	0.795	0.925	0.930
10m/s	0.360	0.395	0.535	0.690	0.705	0.735	0.755	0.890	0.925
15m/s	0.350	0.370	0.510	0.580	0.600	0.635	0.655	0.820	0.910
20m/s	0.300	0.360	0.500	0.530	0.560	0.580	0.650	0.810	0.900

$h_{sp}+2h_n$ is the sum of the hop counts that is required during the transmitting of a RERR to the source node and the hop count that is required during a new search process, when the local repairing process fails.

The recovery time of the local repair is shown in (4) using a success probability of the local repair.

$$T_{AODV\_RL} = \beta T_{AODV\_RLS} + (1-\beta)T_{AODV},$$
where is the success probability of the local repair. (4)

When the local repair fails, the recovery time is the sum of the time which is required to perform the local repair and the time which is required to perform the new search process. Fig. 8 shows the recovery time from the route breakage to the route recovery in AODV with the local repair and in AODV without the local repair. One-hop transmission time(α) is NODE_TRAVERSAL_TIME which is a conservative estimate of the average one hop traversal time for packets and include queuing delays, interrupt processing times and transfer times. α is 40ms[4]. When the success probability of the local repair is less than 0.65, the recovery time in AODV with the local repair is longer than that in AODV without the local repair. The success probability of the local repair depends on density and speed. The node density is the number of nodes within the transmission range of the node[12].

We have simulated the success probability of the local repair depending on the density and the speed using UNIX C. The MANET size is 1000 x 1000 units. The numbers of randomly generated nodes is set to 50. The transmission range is 250 units. Each node has the same speed and moves with random direction at

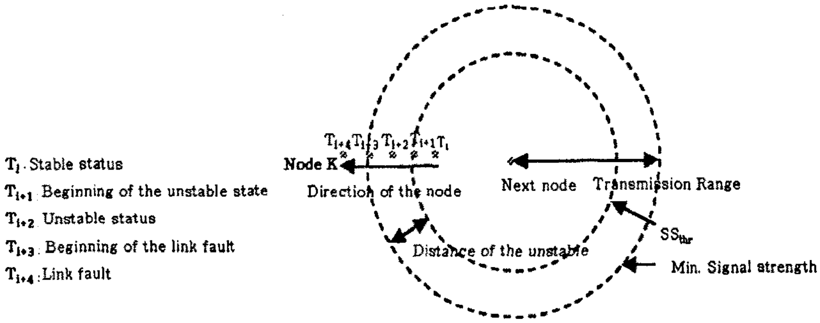


FIGURE 9. The model of the link state

speeds 5, 10, 15 or 20 units per second. As the density is high, the probability of success increases. As the speed increases, the success probability decreases.

3.2. Route recovery of RRAODV

RRAODV avoids the current route from disconnecting. When the signal strength is below the SS_{thr}, the link status is unstable. In fig. 9, node K is going to the opposite direction from the next node. The link status is stable at T_i and the link status is unstable from T_{i+1}. The link is lost at T_{i+3}. Node K starts local repair process at T_{i+1}. If the local repair process succeeds before the link fault, there is no delay in the transmission of packets. If the alternative node selecting process is completed after the link fault, or the selection process fails, some delay is occurred. The delay is calculated by the difference between the time of alternative node selection process and the time of an unstable state.

The time of the first selecting process T_{RRODV_SS1} is shown in (5)

$$T_{RRAODV\_SS1(SelectingSuccess)} = 3. \tag{5}$$

1 of 3 is the processing time to select one of the active downstream nodes within signal strength. 2 of 3 is the time to notify the selected node and the time to receive the reply. The time of the second selecting process after the failure of the first selection process T_{RRAODV_SS2} is shown in (6).

$$T_{RRAODV\_SS2} = (4 + 0.5d_n). \tag{6}$$

1 of 4 is the processing time to decide the first selection process is unavailable and another 1 of 4 is the time to broadcast a SSRQ(Signal Strength Request) packet. d_n is a node density which is the number of nodes in the transmission range. We assume only half of neighbor nodes have connection to any downstream node. Therefore, $0.5d_n$ is the time to receive a SSRP(Signal Strength Reply) packets from its own neighbors. The other 2 of 4 is the time to notify the selected node and the time to receive the reply.

TABLE 2. The success probability β_1 of the 1^{st} selection

Speed	Density								
	4	6	8	10	12	14	16	18	20
5m/s	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.08	0.09
10m/s	0.02	0.04	0.04	0.06	0.11	0.19	0.23	0.25	0.27
15m/s	0.03	0.11	0.15	0.2	023	0.3	0.33	0.35	0.4
20m/s	0.04	0.16	0.24	0.3	0.36	0.42	0.46	0.48	0.51

TABLE 3. The success probability β_2 of the 2^{nd} selection

Speed	Density								
	4	6	8	10	12	14	16	18	20
5m/s	0.98	1	1	1	1	1	1	1	1
10m/s	0.45	0.72	0.96	0.98	0.99	0.99	1	1	1
15m/s	0.23	0.42	0.83	0.94	0.97	0.99	1	1	1
20m/s	0.13	0.33	0.4	0.8	0.9	0.99	1	1	1

The time to process a route reestablishment after the failure of the second selection process T_{RRAODV_SF} is shown in (7).

$$T_{RRAODV\_SF(SelectingFail)} = (2 + 0.5d_n + h_{sp} + 2h_n). \tag{7}$$

$2{+}0.5d_n$ is the time to decide to the first and the second selection process is unavailable. $h_{sp}{+}2h_n$ is the sum of the hop counts that is required during the transmitting of a RERR to the source node and the hop counts that is required during the new search process. The unstable state time T_{us} is the passing time of the unstable area as shown in (8).

$$T_{us} = \text{the distance of an unstable state/speed.} \tag{8}$$

When a link fails in RRAODV, the recovery time is calculated as shown in (9).

$$\begin{aligned} T_{RRAODV} = {} & \beta_1 T_{RRAODV\_SS1} + (1-\beta_1)\beta_2 T_{RRAODV\_SS2} + \\ & (1-\beta_1)(1-\beta_2)T_{RRAODV\_SF} - T_{us}, \\ & \text{where } \beta_1 \text{ is the success probability of the } 1_{st} \text{ selection} \\ & \text{and } \beta_2 \text{ is the success probability of the } 2_{nd} \text{ selection.} \end{aligned} \tag{9}$$

The sum of β_1 and $(1-\beta_1)\beta_2$ and $(1-\beta_1)(1-\beta_2)$ is 1. When T_{RRAODV} become minus, we assume it as zero.

The success probability of the 1^{st} selection(β_1) and the success probability of the 2^{nd} selection(β_2) change depending on node speed, mobility, density, topology and so on. Table 2, 3 are the success probabilities β_1, β_2 depending on node density, speed. As the node density of the nodes is high, the probabilities β_1, β_2 increase. As the node speed increases, the probability β_1 increases and the probability β_2 tends to increase.

TABLE 4. The success probability β_3 of selection process

Speed	Density								
	4	6	8	10	12	14	16	18	20
5m/s	0.88	0.98	0.99	0.99	1	1	1	1	1
10m/s	0.39	0.69	0.94	0.97	0.98	0.99	1	1	1
15m/s	0.28	0.39	0.79	0.914	0.97	0.99	1	1	1
20m/s	0.19	0.31	0.41	0.83	0.86	0.9	0.97	1	1

3.3. Route recovery of ARMP

ARMP mainly consists of two phases, ANDP phase and LRRP phase. The time of ANDF and LRRP phases in ARMP, $TARMP_{SS}$ is shown in (10).

$$T_{ARMP\_SS} = (5 + 0.5d_n). \tag{10}$$

1 of 5 is the time to be required that both end nodes calculate its own mobility. Another 1 of 5 is the time to transmit the mobility value to the other node. Another 1 of 5 is the time that the active node broadcasts a LRRP packet. $0.5d_n$ is the time that the nodes which receive the LRRP packet transmit to the active node the LRRP reply packet. The other 2 of 5 is the time to notify the selected node and the time to receive the reply. The time to process a route reestablishment after the failure of the LRRP phase, T_{ARMP_SF} is shown in (11).

$$T_{ARMP\_SF} = (3 + 0.5d_n + h_{sp} + 2h_n). \tag{11}$$

$3{+}0.5d_n$ is the time to be required to perform the ANDF and the LPPR phase. $h_{sp} + 2h_n$ is the time to be required during the transmitting of a RERR to the source node and the number of the hop counts that is required during the new search process. Therefore, the route recovery time in ARMP is shown in (12).

$$T_{ARMP} = \beta_3 T_{ARMP\_SS} + (1 - \beta_3) T_{ARMP\_SF} - T_{us},$$
where β_3 is the success probability of the LRRP phase. (12)

Table 4 is the success probabilities β_3 depending on node density, speed. As the node density of the nodes is high, the probabilities increase. As the node speed increases, the probability tends to increase.

The fig.10 shows the route recovery time as the density is varied. The speed is set to 15m/s and the distance of the unstable state is set to 7m. The recovery time decreases as the density increases. The recovery time of RRAODV is shorter than that of ARMP or AODV. The fig.11 shows the route recovery time as the node speed is varied. The density is set to 8 and the distance of the unstable state is set to 7m. The recovery time increases as the node speed increases. The recovery time of RRAODV is shorter than that of ARMP or AODV.

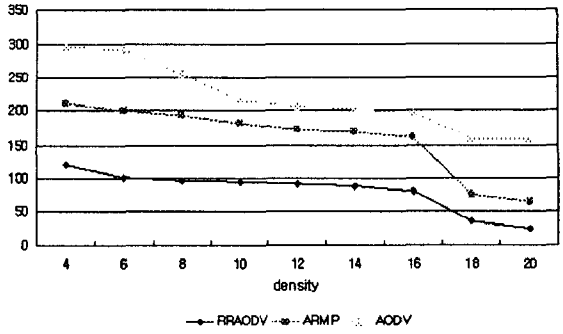


FIGURE 10. The recovery time depending on the node density

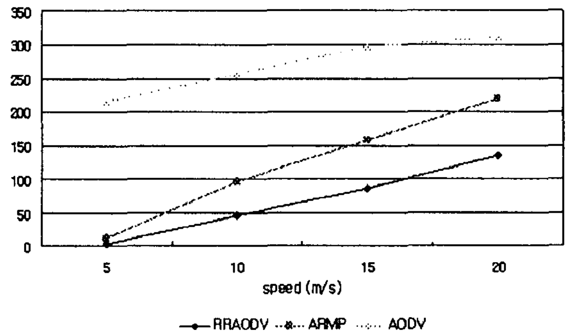


FIGURE 11. The recovery time depending on the node speed

4. Experiments and the results

A computer simulation is derived to evaluate the accuracy of the recovery time formulas of RRAODV, ARMP, AODV using UNIX C. The MANET size is 1000 x 1000 units. The numbers of randomly generated nodes is set to 50. The transmission range is 250 units. Nodes move with random direction at speeds 5, 10, 15 or 20 units per second. In our simulation, we assume that the signal strength depends solely on the distance between the sending and receiving nodes. If a signal is weaker than the threshold of a stable link (SS_{thr}), it considered dropped. The stable distance depending on SS_{thr} is set to 240 units and the one-hop transmission time is set to 40 ms.

The fig.12 shows the comparison of the recovery time in AODV with the local repair, as the node speeds are varied. The two results have a similar tendency as the speed increases. But, there are some time differences. We analyses that this error may be concerned with one-hop transmission time(α). It is the average one hop traversal time for packets including queuing delays, interrupt processing

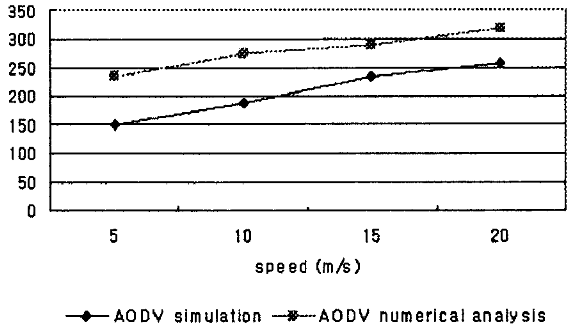


FIGURE 12. The comparison of AODV recovery time

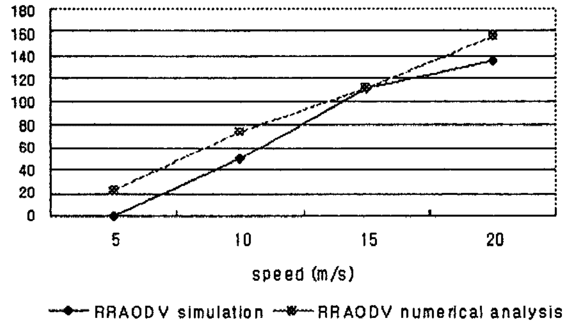


FIGURE 13. The comparison of RRAODV recovery time

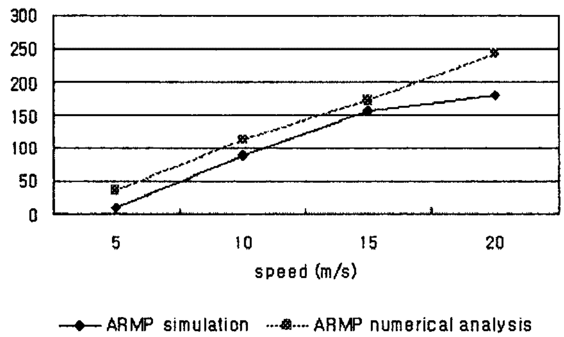


FIGURE 14. The comparison of ARMP recovery time

times and transfer times and variable depending on network condition. But it has a fixed value(40ms) in the numerical analysis.

The fig.13 shows the comparison of the recovery time in RRAODV, as the node speed is varied. The two results also have a similar tendency.

The fig.14 shows the comparison of the recovery time in ARMP, as the node speed is varied. The two results also have a similar tendency, as the speed increases.

5. Conclusions

We proposed numerical analysis method for three adaptive ad hoc network routing protocols for avoiding route breakage. The numerical formulas of AODV, the representative on-demand routing protocol, ARMP, and RRAODV are provided to verify the efficiency of the routing protocols and estimate the performance. The numerical formulas is formed on the basis of hops that the control message is transported. In the result of the numerical formulas, RRAODV has better performance than AODV, ARMP. In comparison the results of the numerical formulas by the results of the simulation, the two results show a similar tendency, but there exists a certain error which may be caused by one-hop transmission time. It is expected that appropriate one-hop transmission time reduces this error. The proposed analytic methods can be modified and applied for other ad hoc routing protocols.

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