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An adaptive clustering routing transition protocol in ad hoc networks

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Abstract

To solve the expansibility problem of traditional flat routing protocols in ad hoc networks, an adaptive clustering routing transition protocol (ACRT) was proposed in this paper, by using the idea of adaptive clustering, routing transition and profits by the merits of passive clustering and gradual clustering. ACRT creates clusters adaptively by real-time apperceiving network scale which can solve the conflict between the expansibility of flat routing protocols and clustering overhead of clustering routing protocols. This mechanism takes the compatibility among different routing mechanisms into account to obtain high routing efficiency. ACRT can eliminate hang-overs of flat routing protocol to reduce the occupancy of resources and storage cost by strict transition strategy. Simulation results show that ACRT has good expansibility and adaptive control action. ACRT is a correct and efficient routing mechanism.

Keywords: Communication technology; ACRT; Routing transition; Adaptive; MANET

1. Introduction

Multi-hop ad hoc networks (MANET) are self-creating, self-organizing and self-administrating without deploying any kind of infrastructure [1]. These characteristics of MANET open out a bright prospect for the applications of military, disaster discovery, commercial, education, which fixed infrastructure is not easily acquired. However, it is a challenging work to design the routing strategies for MANET. The traditional routing protocols that need stable network topology and complicated computation can't work efficiently over MANET (unfit) due to dynamic network topology, limited energy and processing ability.

The core problem lies in routing. Many routing protocols for MANET have been proposed in recent years. These protocols can be classified into two categories based on the manner of drivers: table driven and on-demand driven. The routing mechanisms of table driven (or proactive) routing protocols (e.g., DSDV [2], WRP [3] and OLSR [4]) are based on traditional routing protocols. Table driven routing protocols make each node maintain an updated routing table which it can use to find a path to a destination, based on the periodically exchanging of routing information between the different nodes. The key advantage of the routing protocol is that it can make faster and exact routing decisions. However, the costs of construction and maintenance the route tables that contain connectivity information of whole networks are high. When the network topology changes continually and acutely, the route table cannot converge easily and the routing is inefficient. Therefore, table driven routing protocols are unfit for networks which have large scale or low traffic loads. The main idea of on-demand driven (or reactive) routing protocols (e.g., AODV [5], DSR [6] and TORA [7]) is that a source node obtains a path to a specific destination only when it needs to send some data to it and the nodes do not exchange routing information periodically. Thus this kind of routing protocols can reduce the resources which are used for the maintenance of huge routing tables. On-demand driven routing protocols are fit for MANET which have dynamic topology and limited resources though they add the delay of routing. Most

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researchers prefer to use on-demand driven routing protocols, which have already become the mainstream in area of routing protocol research for mobile ad hoc networks.

From the angle of network structure, routing protocols for MANET can be classified into two categories: flat routing protocols and clustering routing protocols. In flat routing protocols, status of each node is equal and the function is same. The routing discovery (essentially, the routing discovery of on-demand driven routing protocols is based on flooding) and routing maintenance (the exchange of routing information periodically of table driven routing protocols should converge within whole ad hoc networks) will expend many resources in large-scale networks. Therefore, the expansibility of flat routing protocols is not good. Clustering routing protocols divide the network into clusters within which nodes have different functions. The advantages of this structure are: ① reduce redundant flooding efficiently by decreasing the number of nodes which participate in routing calculation; ② lessen influence after change the network topology since localize it within one zone by clustering; ③ simply the functions of nodes that not have to maintain complicated routing info and reduce the number of signal accordingly [8]. ④ easy to manage and easy to use distributed algorithms; have better performance of scalability and is suitable for large-scale network. There are some typical routing protocols based on cluster such as CBRP [9], HSR [10] and CGSR [11].

2. Related work

There have been various ad hoc routing protocols, but most of them have specific application environment and can not do well in any circumstances. For example, the routing discovery that uses expanding ring search [5] based on flooding may decrease the performance of AODV acutely [12]. Since a large number of RREQ have been broadcasted, the flooding causes aggravating overhead and severe congestion when the scale network is large. Table 1 indicated the results of expansibility over the simulation environment in Section 4. All data are the average of five tests. We can see from the table, the performance of AODV reduces severely when the nodes of network are more than 200 such as normalized route request overhead will be more than 0.5; both packet delivery ratio and successful route request ratio will be under 50%; route acquisition time and end-to-end delay will be more than 1000 ms and 3000 ms, respectively.

Recent advances in the portability, power, and capabilities of ad hoc devices and applications have resulted in the proliferation and increased popularity of these devices. As the number of users continues to grow, ad hoc routing protocols will be required to adapt increasingly larger populations of nodes. Conference networking scenarios can require the formation of networks on the order of tens to hundreds of nodes, while many military applications can involve thousands to tens of thousands of nodes. Furthermore, as the deployment of wireless networks becomes more widespread, new applications may encourage the formation of large ad hoc networks. For instance, sensor networks may include thousands of sensors which must be able to self-configure and establish routes. Similarly, military battlefield operations often require the formation of ad hoc networks containing hundreds to thousands of soldiers and personnel. As the key technique of military networks, ad hoc networks must support the cooperation of various branches of the armed forces and joint operations in three-dimensional space. It is necessary for units (including infantry, armored vehicles, communications vehicles, aircraft, ships and weapons) to entry into or withdraws from communication network rapidly and frequently. Thus, how to make ad hoc routing protocols adapt the networks and adjust strategy to achieve optimal routing performance will be a goal for ad hoc routing design.

Some scholars have made attempts on the issue. M. Gerla improved AODV by passive cluster (PC) formation proposed in [13] for reducing redundant flooding of routing requests. On the premise of not increasing any explicit control packets, passive clustering uses on-going data packets that piggyback “cluster related information” (e.g., the state of a node in a cluster, the IP address of the node) to set cluster states for each node. Passive clustering adopts complicated “Gateway Selection Heuristic” and stipulates only cluster head or gateway can transmit RREQ packets in order to reduce the number of flooding and the overhead of networks. Experiments indicate that on-demand driven routing protocols based on passive clustering have superior

Table 1
Expansibility test results of AODV

Nodes	Items						
	Normalized route request overhead	Packet delivery ratio (%)	Successful route request ratio	Route acquisition time/ms	End-to-end delay/ms	Packets delivered	Packets received
50	0.33862	81.76	0.87636	401.52432	1115.30854	500	408.8
100	0.43388	61.26	0.58948	328.98394	1024.27122	1000	612.6
150	0.36312	71.80	0.69338	182.94232	635.15938	1500	1077
200	0.4347	59.33	0.4916	243.59174	798.75896	2000	1186.6
250	0.67844	41.96	0.54534	1184.27396	3653.68988	2500	1049
300	0.67844	20.81	0.30558	1282.81418	5084.7744	3000	624.2
350	0.69502	40.19	0.49254	1104.25498	3353.21448	3500	1406.6
400	0.95662	27.99	0.36182	1291.8695	3958.04676	4000	1119.4

performance in TNP (the total number of packets sent for one broadcast) and NDB (the number of nodes delivered the broadcast). M. Gerla made some detailed descriptions and analysis for passive clustering mechanism in [14,15]. A. Rangaswamy improved and enhanced passive clustering efficiently and solved some problems [16]. For examples, clusters are unstable under low or irregular traffic loads and they may break down frequently; packets arrive out-of-order at the destination and the packets contain different states (i.e., the sending node changed its state between transmission of multiple packets) then the destination node will be misled about the true state of the source node; a loss of critical path to some nodes under certain spatial configurations. However, passive clustering still has some shortcomings such as: ① It still uses flat routing protocols essentially. This means nodes must know more routing information and maintain more entries of route tables compared to clustering routing protocols. ② It constructs excessive overlapping clusters that causes excessive cluster heads and "GW_READY" (preparatory Gateway), increases redundant flooding and difficult for management. ③ It has excessive cluster states that often switch to one another and increase complexity of the algorithm. ④ It affects the performance of data transmission due to extra cluster related information in every packet which will participate in cluster conformation and cluster maintenance.

Zheng proposed gradual clustering routing strategy (AODV-clustering) [17] that constructs clusters by RREP. Each node provides two routing modes: AODV and fast routing search. When nodes within the cluster originate routing requests, they search routes based on fast routing search firstly, then use AODV if fast routing search failed. Gradual clustering routing is a transition strategy from flat routing to clustering routing; therefore it is superior to passive cluster formation in reducing flooding, minimizing the impact of dynamic network topology and enhancing the expansibility. But gradual clustering routing strategy still has some insufficiencies: ① Nodes within clusters have to use two incompatible routing search methods resulting in redundant flooding and routing delay. Especially in initial period of clustering, the probability of failure routing is very high (actually, in gradual clustering routing strategy, the elimination of the cluster conformation delay is at the price of routing failure). ② There are hangovers such as control packets and route table of flat routing protocols which will be in the whole network forever due to the non-strict transition strategy. ③ This strategy is an unconditioned clustering routing protocol which is not suitable for dynamic scale networks.

Both of the above schemes have improved the performance of protocols in large-scale networks by using clusters in order to reduce flooding. However, they are different from method of cluster, routing protocols and so on. The comparison of them can be seen from Table 2 and both of them have merits and faults.

There are close relationship among scale, architecture of network and routing protocols. The scale of network is not controllable to a great extent, but architecture and routing protocols are on the contrary. The existing routing protocols are only suitable for special occasions and it is very difficult to propose some one kind of versatile routing protocol that is able to show perfect performance in all situations. Therefore, it is a novel idea to design the Transition scheme between routing protocols by making use of merits of various protocols in different situations and adaptive network scale. In this paper, we consider the ACRT (adaptive clustering routing transition protocol), in which we designed an adaptive transition strategy based on network scale that is from flat routing to clustering routing on the premise of no influence on data transmission. ACRT profits by the merits of passive clustering and gradual clustering, and overcomes the shortages of them. ACRT has good adaptability that can construct clusters automatically based on the situations of networks.

3. Description of ACRT

3.1. Design principles of ACRT

We analyzed the merits and defects of passive clustering and gradual clustering. From the aspects of accuracy, efficiency, robustness and expansibility, there are some design principles of ACRT:

- Adaptive network scale
  On-demand driven routing protocols (e.g., AODV) show good performance with small-scale network and it is unwise to construct clusters. Because it not only fail to enhance the efficiency of protocols but also increase the cost for construction and maintenance of clusters. But when the scale of network increases to a certain degree, the performance of cluster based routing protocols shows superiority over flat protocols remarkably. Therefore, the routing protocols can keep on working with high efficiency, stability and adaptability if we adopt adaptive clustering scheme.
- PC based conformation of clusters
  Passive clustering uses on-going data packets that piggyback "cluster related information" to set cluster states for each node. It is superior to other cluster conformation algorithms because it need not any explicit control packets.
- Compatibility of flat routing and clustering routing
  In the period of clustering, both flat structure and cluster structure will exist in the network; accordingly, there will be two different routing modes: flat routing and clustering routing. If they are compatible, the probability of routing failure will be reduced and the secondary routing search will be eliminated.
- Strict transition
  ACRT protocol contains two-tier transition: network structures and routing mechanisms. Both of the routing mechanisms have corresponding route table. ACRT adopts gradual reduction strategy of route table, which

can remove the route table entries of flat routing gradually on the premise of no influence on any data transmission. To a certain time, there will be no flat routing related control packets and routing information. However, it implements a unified clustering routing protocol. We call this integrated transition strict transition.

3.2. Mechanisms of ACRT

ACRT is a transition protocol with adaptive and on-demand driven clustering routing. It carries out clustering passively only when satisfies the demand of clustering threshold. It does not require any explicit control packets in the period of clustering. It implements on-demand driven routing protocols: AODV and CBRP, which are widely accepted. ACRT contains two important components: one is the trigger mechanism and clustering conformation, which determine the opportunity and structure of clustering; the other is the strategy of routing transition, which solves the compatibility problem among protocols and the problem of strict transition.

3.2.1. Clustering trigger mechanism and cluster formation algorithm

The routing hops reflect the scale of networks to a large extent; therefore, ACRT takes the routing hops of AODV as the clustering threshold. To increase the payload of packets and the efficiency of data transmission, ACRT uses RREQ and RREP of both AODV and CBRP to construct clusters. Cluster information field in the header is carried by each RREQ and RREP. This field contains the following entries:

- Cluster request flag (CRF), a node decides whether to respond the clustering requests in terms of CRF.
- Cluster setting counter (CSC), a node decides whether to set itself as cluster head according to CSC.
- State of precursory node (SPN), a node decides the state of itself based on SPN.

Each node has a state at any time. They are FLAT, CLUSTER_ HEAD, ORDINARY, GATEWAY, DISTR_GW. The initial state of each node is FLAT.

3.2.1.1. Condition of clustering trigger. ACRT will trigger the conformation of clusters and set CRF as 1, CSC as 2 in the control packets only under following conditions:

(1) The value of "Hop Count" in RREQ of AODV reaches or exceeds the clustering threshold C and such RREQ does not pass through non-flat nodes.
(2) The RREQ of AODV derived from flat nodes passes through non-flat nodes and then reaches to flat nodes for the first time.
(3) The RREQ of CBRP derived from non-flat nodes passes through flat nodes for the first time.
(4) The RREP in which the value of CRF is one reaches to flat nodes for the first time (the value of CRF in RREP generated by any node should be the same as the corresponding RREQ).

Note that cluster conformation only acts on flat nodes.

3.2.1.2. Response to cluster conformation. When the flat nodes receive a RREQ or RREP (no matter AODV or CBRP) and the value of CRF is one, they will response to cluster conformation request. The algorithm is described as follows:

(1) If it is a initiative node and satisfies the condition of clustering trigger, then sets itself as cluster head and set SPN as "CLUSTER_HEAD" in RREQ or RREP which will be send out.
(2) If the value of CSC is zero, then sets itself as cluster head, resets CSC as two and sets SPN as "CLUSTER_HEAD" at the same time.
(3) If the value of CSC is non-zero, such node sets its own state based on SPN first, then reduces the value of CSC by one and sets SPN as its own state.
(4) If such node is the destination of RREQ or RREP and the value of CSC in RREQ or RREP is less than or equal to one, then sets itself as cluster head.

Figs. 1 and 2 indicate the examples of cluster conformation with trigger condition (1) and trigger conditions (2) and (3), respectively.

Table 2
Comparison of passive clustering and gradual clustering

Items	Protocols	
	Passive cluster	AODV-clustering
Packets piggyback cluster related information	All packets	RREP of AODV
Selection of cluster head	Every one hop	Every two hops
Maintenance of clusters	All packets	Special control packets
Number of routing protocols	1	2
Type of routing protocols	Flat routing	Flat and clustering routing
Gateway curtailment	Yes	No
Additional control packets	No	Yes

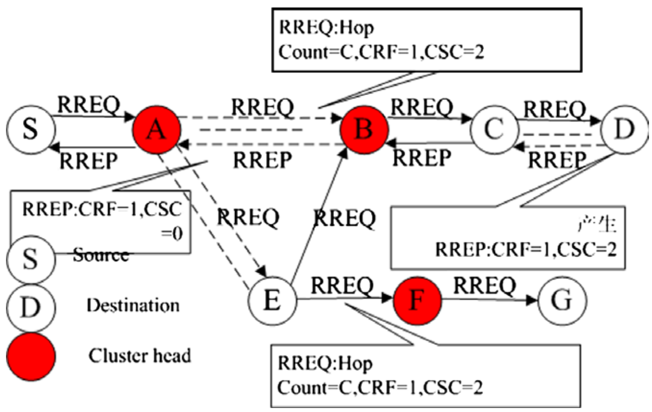

Fig. 1. Example of trigger condition (1) and (4).

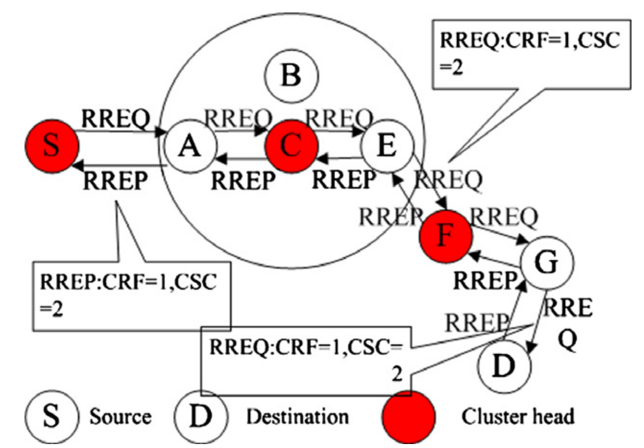

Fig. 2. Example of trigger condition (2) and (4).

3.2.1.3. Arrangement of clustering state. The cluster conformation of ACRT is based on PC and each node collects neighbor information through promiscuous packet receptions. First, to form a basic clustering structure, each node sets its own basic state (CLUSTER_HEAD or ORDINARY) based on the current state and SPN in RREQ or RREP. Then ACRT meliorates the clustering structure by using the cluster formation method of CBRP [9] (It is different from CBRP that ACRT doesn't use LID [18] to construct clusters, but uses the CSC in RREQ or RREP). The specification is as follows:

(1) If the current state is "FLAT" and the SPN in received RREQ or RREP is "CLUSTER_HEAD", the node will set its own state as "ORDINARY", otherwise, it won't change its own current state.
(2) The node which has joined to cluster uses Hello messages of CBRP to select clustering gateways and distributed gateways for routing.

3.2.2. Routing transition strategy

In the process of clustering, there are flat structures and cluster structures at the same time and we adopt AODV and CBRP as the routing protocols for both structures. The goal of routing transition strategy is to make both of them compatible and transit to CBRP gradually.

3.2.2.1. Description of AODV in ACRT. If the source of routing request is a flat node, ACRT will use AODV to search the route. To reduce the flooding, The RREQ, which has entered into clustering structure only were retransmitted by cluster heads, gateways or distributed gateways(note, the boundary nodes which adjoin flat nodes are regarded as gateways).

3.2.2.2. Description of CBRP in ACRT. If the source of routing requests is a node within cluster, then ACRT uses source routing protocol CBRP to search the route. The RREQ of CBRP fills the addresses of cluster heads and corresponding gateways passed through. When the target of the Request receives the RREQ, it sends out an RREP packet to source as a reply by reversed address list (the RREP of traditional CBRP only copies the addresses of cluster heads). Each data packet is transmitted by way of source routing. When the RREQ of CBRP enters into flat structure, ACRT still uses source routing, but the route will not follow the sequence pattern as cluster header → gateway → (distributed gateway) → cluster header → gateway → . . .→.

To limit the number and scope of flooding, we introduced a special expanding ring search algorithm. In an expanding ring search, the originating node initially uses a TTL = TTL_START in the RREQ packet IP header and sets the timeout for receiving a RREP to RING_TRAVERSAL_TIME milliseconds. The TTL_VALUE used in calculating RING_TRAVERSAL_TIME is set equal to the value of the TTL field in the IP header. If the RREQ times out (RING_TRAVERSAL_TIME) without a corresponding RREP, the originator broadcasts the RREQ again with the TTL incremented by TTL_INCREMENT. This continues until the TTL set in the RREQ reaches TTL_THRESHOLD, beyond which a TTL = NET_DIAMETER is used for each attempt. This special expanding ring search is different from traditional algorithms due to the cluster heads in CBRP, which contain information within two hops and show superiority over other nodes in the ability of routing search. Therefore, we regard a cluster as a flat node. RREQ reduces the value of TTL_VALUE by one whenever it passes a cluster or a flat node. ACRT can avoid redundant large-scale flooding and corresponding decrease of performance by using this special expanding ring search.

3.2.2.3. Strict clustering transition. ACRT is a strict clustering transition protocol and the control packets and route table of flat routing protocol should be eliminated finally. If a node receives a RREP of CBRP, it will examine its own route table. If such node has an entry of which the destination is in the reverse address list of RREP, it will remove the entry from route table. Note that Fig. 3 assumes S as routing source and D as destination. The

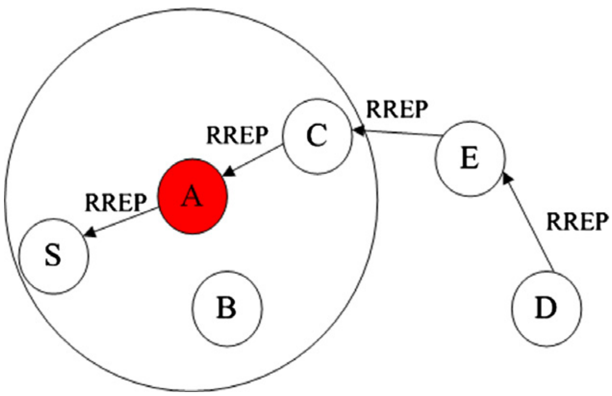

Fig. 3. Example of RREP generated from node D.

Table 3
Removed entries of route table

Nodes	Destinations of entries removed by RREP			
D	S	A	C	E
E	S	A	C	D
C	S	A	E	D
A	S	C	E	D
S	A	C	E	D

RREP that contains reverse address list is generated from node D and passes by nodes D, E, C, A, S, then it removes certain entries of corresponding route table which has been listed in Table 3; The node will stop the timer for Hello messages and do not generate control packets of flat routing protocol such as Hello messages and RRER when it has not any route table entry of AODV.

4. Simulation and analyses

Our simulation is based on ns-2 [19] network simulator. Ns-2 provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. Firstly, we simulate AODV, AODV-clustering, PC and ACRT with fixed network scale and analyze their performance in metrics of route acquisition time, packet delivery ratio, route acquisition time, end-to-end delay and RREQ's initiated. Secondly, we simulate above four routing protocols with dynamic network scale to test the adaptive control action of ACRT.

4.1. Fixed network scale

To make comparison simple, we simulated AODV, AODV-clustering, PC and ACRT (the clustering threshold C was 10) with the same environment. In our experiments, 50, 100, 150, 200 nodes are placed randomly within $1000 \times 1000\ m^2$ terrain and 250, 300, 350, 400 nodes are placed randomly within $2000 \times 2000\ m^2$ terrain. The effective transmission distance of each node reaches up to 250 meters and the capacity of each packet is 100 bytes with packet rate 1pkt/min. We used 802.11 DCF as link layer protocol. The random-way point model [20] is used for node mobility. The moving speed of each node is between 0 m/s and 20 m/s and the pause time is 100 s. Each simulation runs for 600 s. All the data is the average of 5 simulation results.

The simulation results can be shown in Figs. 4–9. We can see AOV-clustering and PC can not improve network performance with small network scale. This is because these two protocols are unconditional clustering protocols and the costs for clustering construction and maintenance offset the most benefits of clustering with small network scale. ACRT is an adaptive clustering protocol that can explore network scale automatically to implement suitable routing strategy without priori knowledge of network size. Therefore, ACRT demonstrates the stability and efficiency persistently.

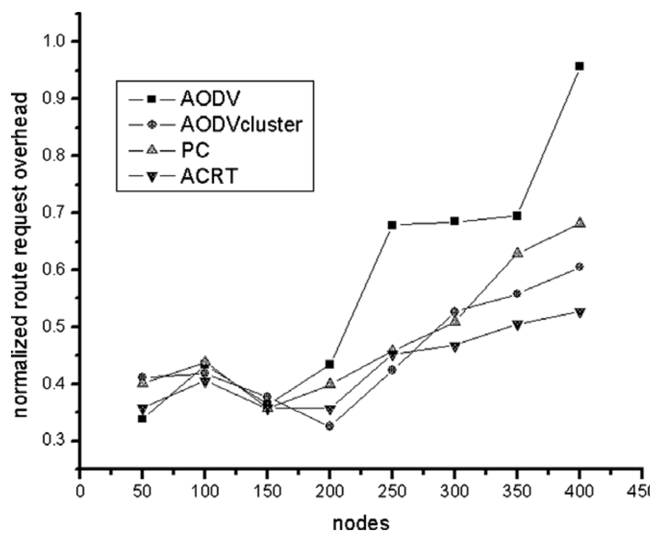

Fig. 4. Normalized route request overhead.

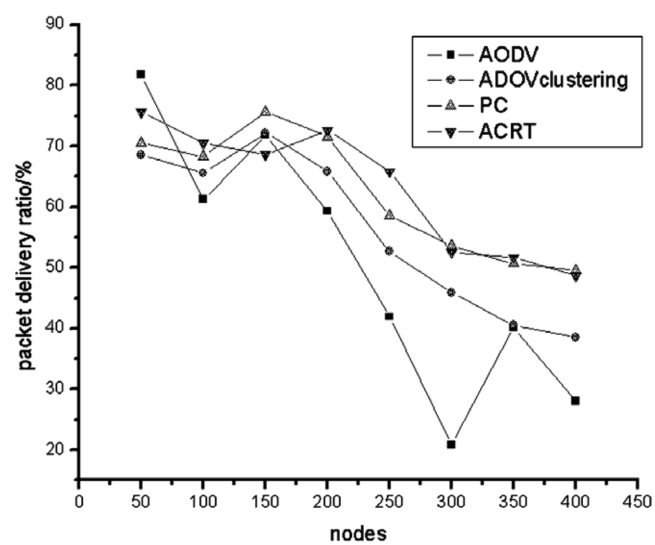

Fig. 5. Packet delivery ratio.

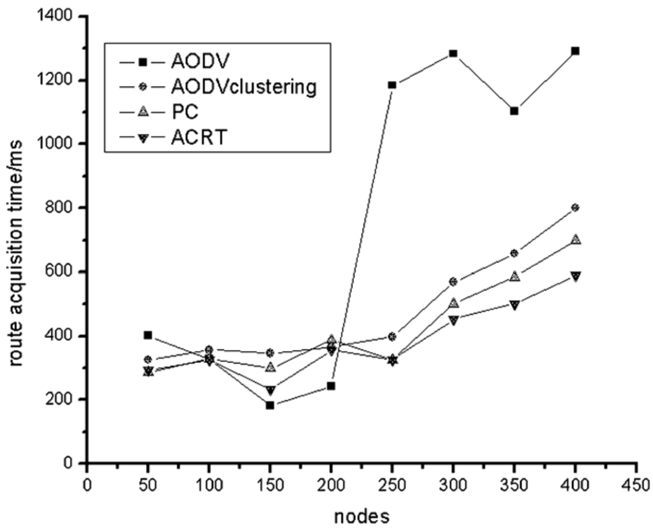

Fig. 6. Route acquisition time.

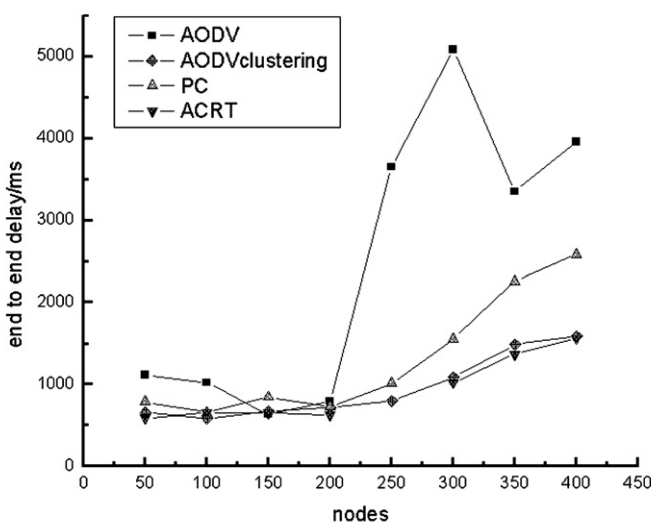

Fig. 7. End-to-end delay.

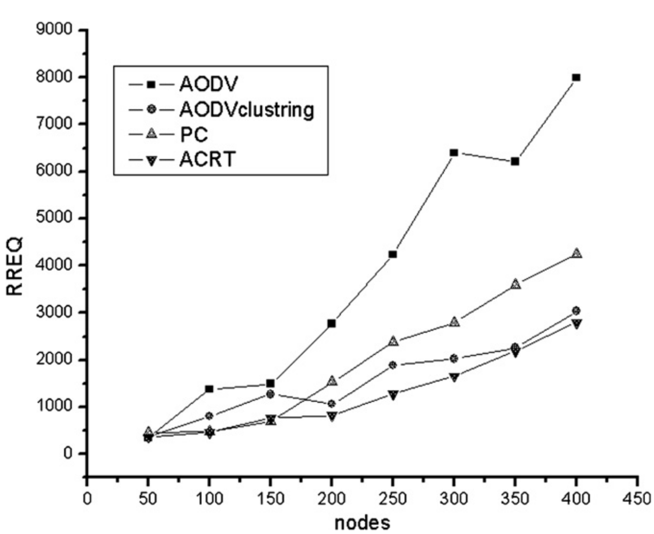

Fig. 8. Quantity of RREQ.

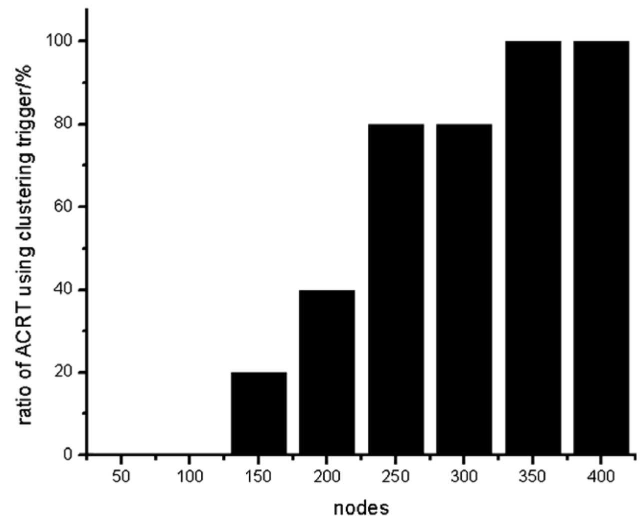

Fig. 9. Ratio of ACRT using clustering trigger.

Fig. 4 shows normalized route request overhead protocols with different network scale. AODV has the highest overhead with the size of networks. Since large numbers of RREQ in AODV have been broadcasted, the flooding causes aggravating overhead and severe congestion with large-scale network. The route request overhead of PC is only better than AODV. It is because there are more nodes involved in routing search due to a lot of candidate gateway which also add the overhead. The route request overhead of AODV-clustering is better than above two protocols. But there is secondary routing search when applying AODV-clustering which adds the route request packets. ACRT overcomes these shortages and has the lowest route request overhead.

Fig. 5 indicates the packet delivery ratio. PC and ACRT show prominent superiority in this metric with large-scale networks. Even with 400-node network, the packet delivery ratio of them still higher than 50%. In most situations, packet delivery ratio of AODV is the lowest. This is because there will be lots of route requests flooded in network which have great influence on data packets transmission. However, AODV-clustering is not ideal in this metric either. The secondary routing search and the hangovers of flat routing protocol caused by non-strict transition cause the AODV-clustering consume part of ad hoc network resources.

Fig. 6 shows the comparison of protocols in route acquisition time. We can see from the simulation results that the route acquisition time of AODV is much more than the other three protocols based on clustering which can reduce route acquisition time under 800 ms efficiently. ACRT has the least route acquisition time. The secondary routing search of AODV-clustering adds the route acquisition time. There is additional process time for each packet in PC which affects the performance of PC.

Fig. 7 indicates that both ATRT and AODV-clustering have superiority in end-to-end delay test. The end-to-end delay of AODV increased severely when the scale of network expands. The end-to-end delay of PC is increased because: each packet has clustering information and extra process time; the route found is not an optimal one due to excessive overlapping clusters and gateways.

Fig. 8 shows the quantity of RREQ broadcasted (contain the RREQ relayed). The RREQ number of this four routing protocols increased with the size of networks. The RREQ quantity of AODV increased significantly faster than other three protocols. This indicated that the large quantity of route queries caused by on-demand flat routing protocols was the main reason which resulted in significant performance decline with large-scale networks. PC caused more RREQ compared with other two protocols based on clusters. This related to the structure of the clusters and the number of gateway created by PC. ACRT and AODV-clustering are better than above two protocols in the respect of controlling RREQ flooding and the RREQ quantity is still under 3000 with 400-node network.

Fig. 9 shows the ratio of ACRT using clustering trigger in five independent simulations with different size networks. We can see this ratio increases gradually with the size of networks. This indicated that ACRT could explore network scale automatically to implement suitable routing strategy without priori knowledge of network size. Of course, besides the number of nodes, the transmitting power of nodes and the network scene can influence the clustering trigger.

4.2. Dynamic network scale

To test adaptability of ACRT with dynamic network Scale adaptability, we also simulated above four routing protocols with dynamic network scale. We designed the simulation scene with dynamic network scale. There were 50 initial nodes in the network. We put 25 nodes into the network every 60 s until 400 nodes. We collected data every 60 s within total 900s simulation time. Other setting and statistical method is same to those with fixed network scale.

The simulation results can be shown in Figs. 10–13. The data is the average value of collection for the last time. The results shown that AODV and ACRT were superior to AODV-cluster and PC based on unconditional clustering with small-scale network. This is because it is relatively expensive to construct and maintain clusters with small-scale network. However, the clustering routing protocols show superiority over AODV with the size of network. ACRT has better expansibility than AODV-cluster and PC. This is because ACRT creates rational structure of clusters and does not have hangovers caused by flat routing protocol. Simulation results show that ACRT can maintain routing performance stably with increasing network environment. Fig. 13 shows the time for clustering trigger of ACRT in five independent simulations.

The simulation results show that ACRT can integrate the advantages of flat routing and clustering routing. ACRT can sense the change of network in real-time and transit to clustering routing protocol adaptively. Analyzing

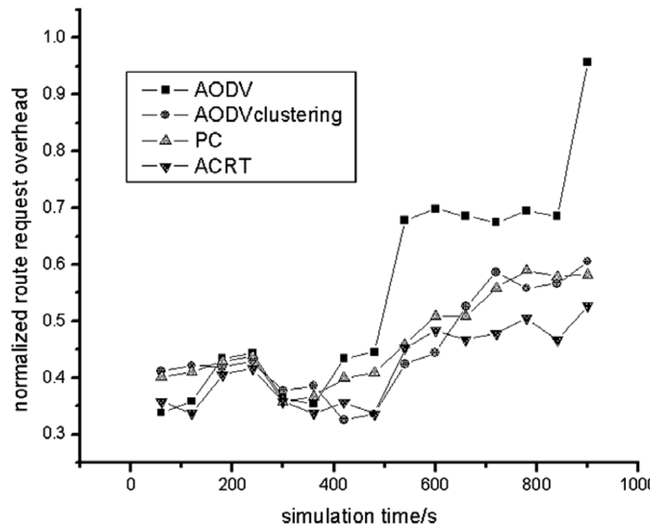

Fig. 10. Normalized route request overhead.

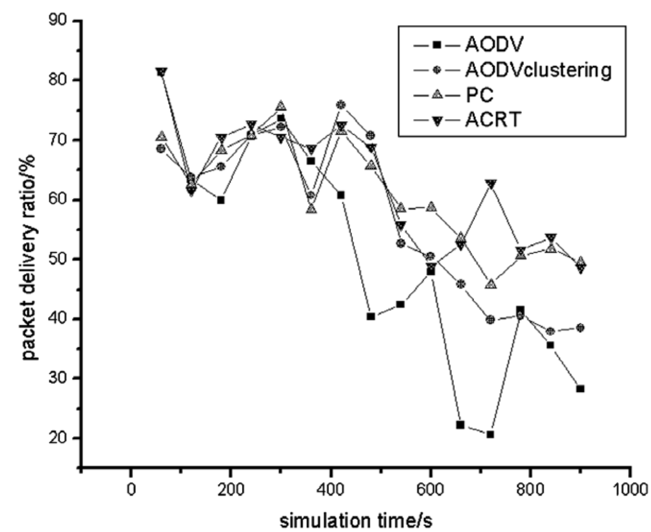

Fig. 11. Packet delivery ratio.

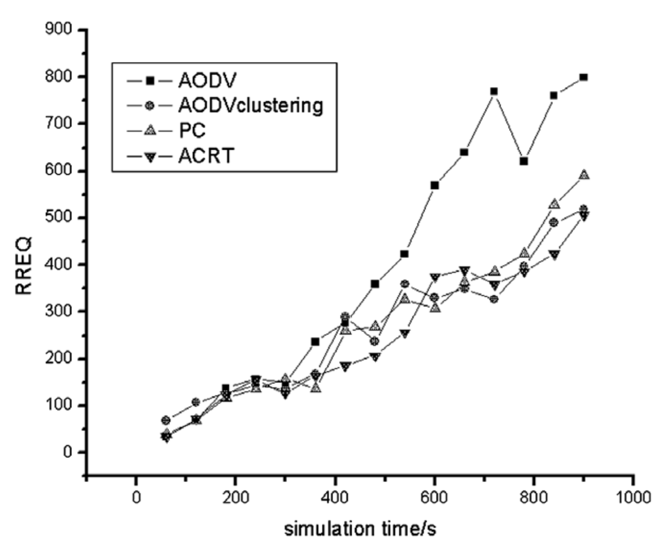

Fig. 12. Quantity of RREQ.

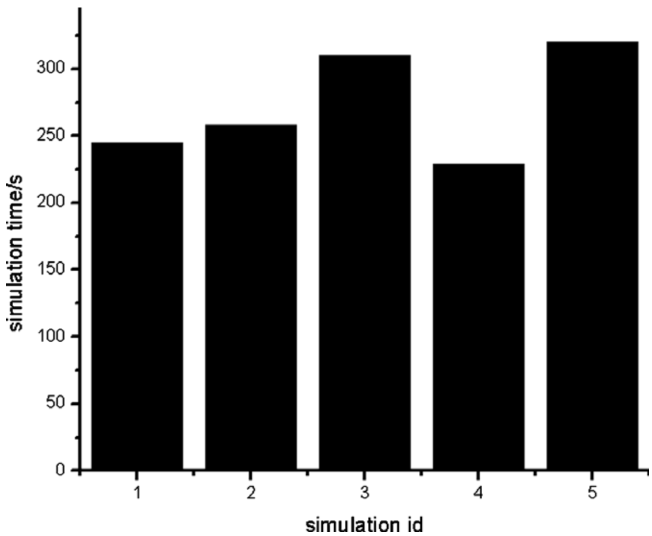

Fig. 13. Time for clustering trigger of ACRT.

design principles of ACRT, we can know that it is a transition protocol from AODV to CBRP actually. Thus, the performance of ACRT is equal or equivalent to AODV with small-scale network and is equal or equivalent to CBRP with small-scale network. Although there are no breakthroughs in respect of routing performance essentially, but ACRT enhances the adaptability greatly and can be applied to the environment that network will change frequently such as military applications.

5. Conclusion and future work

An adaptive clustering routing transition protocol was proposed in this paper, by using the idea of adaptive clustering, routing transition and profits by the merits of passive clustering and gradual clustering. We make a series of simulations for ACRT, AODV, AODV-clustering and PC with fixed scale networks and dynamic scale networks. Simulation results indicate that ACRT has prominent superiority in expansibility and is a correct and efficient routing scheme.

Clustering threshold C is an important parameter for ACRT. Rational value of clustering threshold can improve the stability and efficiency of ACRT. Modeling and logical inference between clustering threshold, network scale and performance metrics of routing and exploring the method to optimize clustering threshold are our future work.

In addition, we plan to design the routing transition protocol from clustering routing to flat routing in order to construct an integrated and bidirectional adaptive routing scheme.

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