VIRTUAL CELL LAYOUT BASED DYNAMIC SOURCE ROUTING ALGORITHM FOR THE MOBILE SUBSYSTEM OF THE NEXT GENERATION TACTICAL COMMUNICATIONS SYSTEMS

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ABSTRACT

In this paper, virtual cell layout (VCL) based dynamic source routing (VB-DSR) technique is introduced for the mobile subsystem of the next generation tactical communications systems. VB-DSR uses dynamic source routing (DSR) protocol over VCL structure, which is a resource management and clustering technique for tactical communications. The application of the third generation personal communications services to the tactical communications is enabled through a hybrid, i.e., ad hoc and cellular, infrastructureless architecture by VCL. VB-DSR enhances the schemes for the ad hoc components of this architecture. The performance evaluation of the proposed technique shows that the VB-DSR is scalable for tactical communications.

INTRODUCTION

Many routing techniques and schemes are proposed for mobile ad hoc networks [1], but they fall into some drawbacks in subjects of scalability, efficient route construction and maintenance, and efficient use of resources (bandwidth, energy, memory, etc.) for tactical communications. The tactical communications architecture must be flexible and rapidly deployable, use resources efficiently, and serve to a large number (i.e., thousands) of mobile units, which have different mobility and call patterns [2, 3]. Moreover, the system must preserve silence and apply the electronic counter measures techniques as required.

Virtual cell layout (VCL) is proposed as a resource management and clustering scheme for the mobile subsystem of the next generation tactical communications systems in [4]. VCL approach enables the application of the third generation personal communication services (3G PCS) technologies to the tactical communications systems. In this paper, we propose an approach called VCL based dynamic source routing (VB-DSR), which uses dynamic source routing (DSR) [5] protocol over Virtual Cell Layout (VCL) structure. VB-DSR is a two level hierarchical cluster-based scheme that provides almost full connectivity, efficient resource management and ability to access 3G PCS systems. DSR is evaluated as an efficient routing protocol in a multi-hop ad hoc network environment [6-10]. However, DSR is not simulated for large sized networks, which have thousands of nodes. VB-DSR is designed for such a case.

Our paper is organized as follows: The VCL scheme is introduced in Section 2. The algorithms, protocols and data structures related to VB-DSR are explored in Section 3. The numerical results from our simulations are given in Section 4. We conclude our paper in Section 5.

THE VIRTUAL CELL LAYOUT BASED MOBILE SUBSYSTEM FOR TACTICAL COMMUNICATIONS

A VCL based mobile communications system [4] is a multi-level hierarchical cluster-based architecture. It has a rapidly deployable mobile infrastructure, and uses both cellular and ad hoc techniques. In VCL, the communication area is covered with fixed size hexagons called virtual cells. The available spectrum and CDMA codes are assigned to these hexagons according to the N=3 frequency reuse plan. Radio access points (RAPs), i.e., mobile base stations, and man packed radios (MPRs), i.e., mobile terminals, use the radio resources assigned to the virtual cell where they are present.

A RAP constitutes a real cell by using the radio resources assigned to the virtual cell where it is located. The real cell created by a RAP, may have different cell size than the size of a virtual cell, and moves over VCL as the RAP moves. MPRs are the mobile terminals of the system. They generally access the network through RAPs. In [4], new ad hoc clustering techniques are also proposed for the MPRs that cannot access a RAP. These algorithms create MPR clusters where one of the MPRs becomes the cluster head.

VCL is composed of four tiers; man packed radio tier (MPRT), radio access point tier (RAPT), unmanned aerial vehicle tier (UAVT), and satellite tier (SATT). UAVT and SATT are the overlay tiers. MPRs are registered to the RAPT cells whenever possible. If there is no RAPT cell to be registered, MPRs try to be registered by an MPRT cell. If an MPR cannot access an MPRT or a RAPT cell, it creates a new MPRT cell and tries to connect this new cell to the lowest (next) possible overlay cell. MPRs handoff between the cells as they move. They can also handoff between upper or lower tiers. The details about the VCL based architecture are in [4].

VIRTUAL CELL LAYOUT (VCL) BASED DYNAMIC SOURCE ROUTING (VB-DSR)

We modify both VCL and DSR to create a simpler and more robust architecture. VB-DSR differs from VCL by its structure and the algorithms used by MPRs. MPRs in the coverage area of a RAP constitute clusters by using VCL as shown in Figure 1. They communicate with each other through RAPs. However, MPRs that do not have an access to a RAP do not attempt to get organized into clusters as they do in VCL approach, but use DSR algorithm to reach the closest VCL cell. In VB-DSR, an MPR can be in one of four states as illustrated in Figure 2. The TURNEDOFF and STANDBY states are the initial states where MPRs do not communicate with the others. Subscribers can use MPRs when they are in RUNLINKED and RUN states. The MPRs in RUN state are the members of VCL cells. On the other hand, the MPRs in the RUNLINKED state are needed to be relayed to reach a VCL cell, i.e., a RAP.

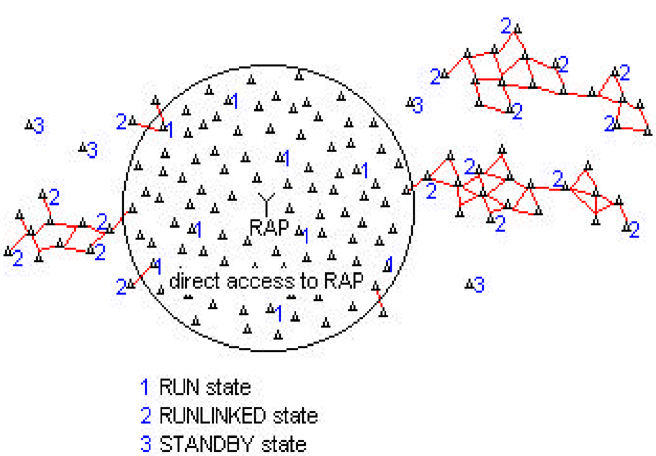

Figure 1 Clustering in VB-DSR.

The main modification we bring to DSR is on packet dissemination processes. In VB-DSR, packets are disseminated throughout the network in a controlled manner. The MPRs in RUN state send their control packets to the RAP that they access. RAPs distribute their packets throughout the network. Only the nodes in the address list of the packet receive it. On the other hand, the MPRs in the RUNLINKED state broadcast their packets.

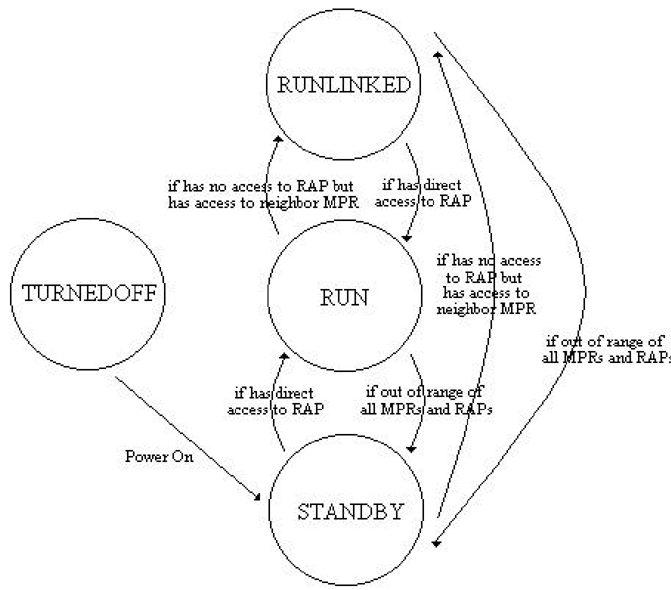

Figure 2 State transitions for MPRs.

Route Discovery Process

In VB-DSR, route discovery process is the same as in DSR, but route maintenance process is modified for VCL. Each MPR and RAP maintains a route cache, a route request table, a send buffer and a retransmission buffer as in the DSR protocol. Size of the buffers, the protocol constants, and applied packet process policies are as defined in [5]. We use a link cache organization to store learned routes in the route caches.

Route search process is executed incrementally as in DSR. At a call request, an MPR in the coverage area of a RAP first checks its route cache to find a route to the destination. If it has, it uses that route without initiating route search process. If it cannot find a route to the destination, it sends a route search packet addressed to the attached RAP. The source MPR iterates route search process as long as the route is not found. At iterations, time to live value (TTL) of the route search packet and reply waiting time of route request table are exponentially incremented. Therefore, a controlled route search process is executed avoiding message flooding throughout the network. The RAP receiving the route search packet searches its route cache. If it finds a route, it sends back a route reply packet addressed only to the source MPR, else broadcast the search packet to other RAPs and to all MPRs in its coverage area. Other RAPs receiving the packet search their route caches. If one of them finds a route to destination, it sends a route reply back to the source MPR by using the accumulated route on search packet.

The RAPs that do not have a route to destination broadcast the search packet to the MPRs under their coverage area. Hence, all the MPRs in the coverage area of a RAP will receive the search packet. Since almost all MPRs are in the coverage area of RAPs, or at least one of them has a path to destination, the destination is found. The MPRs in the RUNLINKED state transmit hello packets when they enter to a new VCL cell, or if they do not receive any packet within a time interval. Hence, the neighbors of the MPRs in the RUNLINKED state know about them. Hello messaging cost remains low because the number of MPRS in the RUNLINKED state is low.

Route Maintenance Process

Packet salvaging is not used for route maintenance because the route acquisition latency is low. Routes are re-discovered on route breakings. Route re-discovery brings a negligible cost to the system, moreover, avoids the possible route maintenance overhead and provides more robust packet delivery.

Route Construction

Route discovery in VB-DSR is consisted of two phases as in DSR: (1) Non-propagating route request phase, (2) propagating route request phase. Therefore, we classify the route replies as:

- ***Neighbor reply:*** This is the route reply sent by a neighbor node of the source, if the destination is itself or if it has a route to the destination.
- ***Cache reply:*** This route reply is produced by the nodes between the source and the destination, i.e., intermediate nodes.
- ***Destination reply:*** This is the route reply sent by the destination.

Routes are constructed in the address field of the reply messages. In VB-DSR, RAPs know the MPRs in their coverage area. Therefore, most of the routes are constructed by using the data in the cache of RAPs. Hence, most of the reply messages are created by RAPs, which are the neighbor nodes of MPRs in their coverage area. This precludes the route search process to spread out the network.

PERFORMANCE OF THE PROPOSED SYSTEM

In order to evaluate the performance of the proposed system, Computer Aided Exercises Interacted Tactical Communications Simulation (CITACS) [11] is used. CITACS interacts with real computer aided military exercises to obtain data related to the movement and the posture of the military units. This data is used to generate realistic mobility, call and availability patterns. We experimented with three different scenarios in our performance evaluation studies. The number of units used in scenarios is given in Table 1. RAPs are deployed with battalions.

Scenario #	# of Units	# of RAPs	# of MPRs
1	6	4	694
2	15	11	1895
3	28	20	3452

Table 1 Scenarios experimented in the simulation.

In simulations, we assume that RAPs can access each other. The latency for any packet between two RAPs is taken as 2 ms. The transceiver range of MPRs in the RUNLINKED state is 250m. The transceiver ranges up to 2000 m. are experimented in the simulations for the MPRs in RUN state. Packet types and packet sizes are as in [5]. Hello packets are treated as route request packets. Data packets are 256 bytes long and sent from each pair of the connection at every 250 millisecond (ms).

Route Acquisition Latency

We use the first reply to a route request to calculate the latency. DSR assumes that the first route reply is received from the shortest route. The latency between the transmission of the route request packet and the arrival of route reply packet includes propagation delay, queuing delay and retransmission delay. Latency increases as the number of hops or packet size increases.

	Latencies (ms)			Total Calls Generated	# of Replies		
	Min	Max	Ave		Neigh.	Inter	Dest.
Sce-1	18	209	53.88	5841	3359	307	1591
Sce-2	18	210	57.52	13076	7460	674	3827
Sce-3	18	251	55.48	19829	11728	805	6026

Table 2 Latency and route reply statistics.

In Table 2, we summarize the results from the latency tests and present the route reply statistics. Route reply statistics shows that a significant amount of route is constructed by the *neighbor replies*, which indicates only a limited number of nodes are involved in most of the route discovery processes.

The latency distributions for Scenario-3 are shown in Figure 3. The x-axis represents the latencies in route search processes. *All replies* represent the number of connections established using the routes constructed by all types of reply messages. *Destination replies* represent the number of connections established by using the routes constructed by only the reply messages returned from destinations.

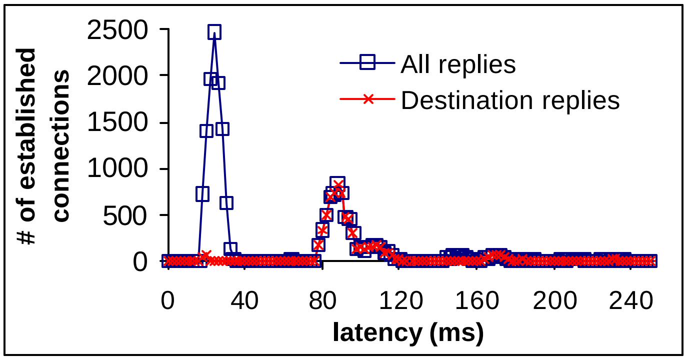

Figure 3 Latency distributions for Scenario-3.

The number of connections established is high for the latency is around 30 ms and around 90 ms. When the latency is around 30 ms, *destination replies* are very low. On the other hand, *all replies* are high. The difference gives the number of routes constructed by the replies returned from neighbor and intermediate nodes. This shows that almost all of the routes are constructed by the route cache information of neighbor nodes and intermediate nodes. When the latency is higher than 40 ms, *all replies* become equal to *the destination* replies. It means that all of the replies are coming from the destination nodes. Therefore, we can say that most of the routes are constructed by the route information of the neighbor and the intermediate nodes within 40 ms, and the remaining routes are constructed by the replies from the destination nodes within 120 ms. Low latencies are the result of short routes. As shown in Table 3, routes are 5-hops long at most and 2-hops long in the average. It appears that the routes remain short as a result of the usage of the VCL structure.

	Route Lengths (# of hops)		
	Minimum	Average	Maximum
Scenario-1	1	2,019	5
Scenario-2	1	2.055	5
Scenario-3	1	2.041	5

Table 3 Route length statistics.

Short routes reduce the route construction latency. Nodes in VB-DSR can learn network topology. They cache the routing information in their route cache, and construct the routes by this topology information. This decreases the route construction latency, increases cache-hit ratio, and reduces the routing overhead.

	Total Calls Generated	Cache Hits			
		Total	Own	Neigh.	Inter.
Scenario-1	5841	4296	630	3359	307
Scenario-2	13076	9328	1194	7460	674
Scenario-3	19829	14187	1654	11728	805

Table 4 Cache hit statistics.

The statistics about route cache hits is given in Table 4. It is shown that a large amount of route to destination is found in nodes' route caches. The latency can be decreased and the cache hits can be increased by optimizing the size of the route caches in RAPs, and higher cache hit rates can be achieved by using better route caching strategies [12].

Routing Overhead

Routing overhead presents the scalability of the proposed approach and its efficiency in terms of power consumption. We measured the routing overhead as the fraction of routing packets to total sent packets in terms of bytes. We present the results from the tests carried out for this metric in Figure 4.

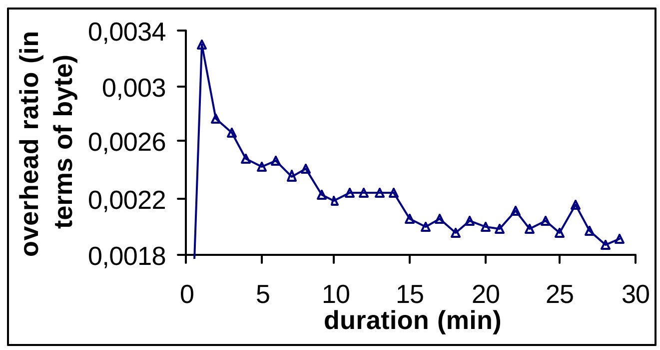

Figure 4 Routing overhead (Scenario-3).

The x-axis shows the simulation time in minutes. There is a sharp routing overhead increase in the beginning of the simulation. However, as the simulation time passes, the routing overhead decreases. At the beginning of the simulation, none of the nodes has any topology information. Therefore, more routing packets are sent to discover routes to unknown destinations. As the time passes, nodes learn the topology by caching the captured route information to their route caches. Therefore, routing overhead decreases as the simulation time passes.

Packet Loss Rate

The packet loss rate versus simulation time is shown in Figure 5. It is shown that almost every packet reaches to the destination with a delivery ratio over 99,9%. Packet losses are generally observed in transmissions between

RUNLINKED state MPRs due to collisions. In the coverage area of a RAP, nodes use CDMA technique as the multiple access schemes and only a small number of nodes remain out of coverage area of RAP. Therefore, only a small number of nodes use CSMA/CA technique. On the other hand, DSR protocol avoids nodes from unnecessary transmissions. As a result, packet loss rates remain very low. No packet is dropped due to the buffer timeout.

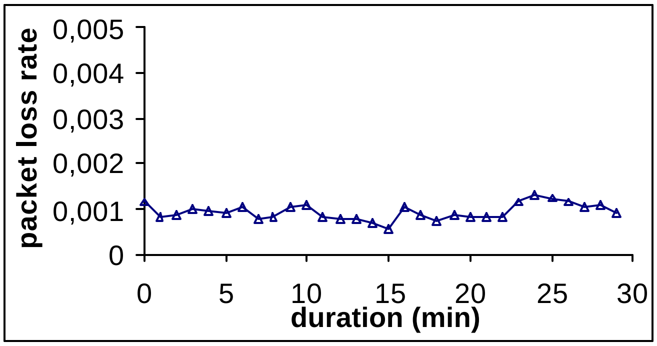

Figure 5 Packet loss rates (Scenario-3).

CONCLUSION

In this paper, we propose an approach named VB-DSR for mobile subsystem of the next generation tactical communications systems. VB-DSR uses Dynamic Source Routing protocol over Virtual Cell Layout, which is proposed as a resource management and clustering scheme. VCL enables the application of third generation personal communication services (3G PCS) technologies to the tactical communication systems. Our study is focused on the mobile terminals (i.e., MPRs), which cannot attach the mobile base stations (i.e., RAPs). We use the dynamic source routing protocol for these nodes.

We evaluate the performance of our approach by simulation. In our system, route acquisition latencies remain very low since most of the routes are constructed by the cache information of neighbor nodes. From the latency and cache-hit results, we conclude that the nodes have the ability to learn the network topology. Results show that VB-DSR has low packet loss rate because of the efficient resource management. Routing overhead is very low in spite of source routing. VB-DSR appears as a scalable mobile subsystem for tactical communications.

REFERENCES

[1] C.R. Perkins, 2000. Ad Hoc Networks, Addison-Wesley, Boston.

[2] P.F. Saas and L. Gorr. Communications for the Digitized Battlefield of the 21st Century, IEEE Communications Magazine, 86-95, October 1995.

[3] P. Saas. Communications Networks for the Force XXI Digitized Battlefield, In ACM Baltzer Mobile Networks and Applications Journal, 139-155, (4) 1999.

[4] E. Cayirci and C. Ersoy. Application of 3G PCS Technologies to Rapidly Deployable Mobile Networks, IEEE Network Magazine, to appear.

[5] D.B.Johnson and D.A. Maltz. Dynamic Source Routing in Ad Hoc Wireless Networks, In Mobile Computing, edited by T.Imielinski and H. Korth, Chapter 5, Kluwer Publishing Company, 1996, pp. 153-181.

[6] D. Maltz, J. Broch, J. Jetcheva and D.B. Johnson. The Effects of On-Demand Behavior in Routing Protocols for Multi-Hop Wireless Ad Hoc Networks, Internet Draft.

[7] E.M. Royer and C-K. Toh. A Review of Current Routing Protocols For Ad Hoc Mobile Wireless Networks, Internet Draft.

[8] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek and M. Degermark. Scenario-based Performance Analysis of Routing Protocols for Mobile Ad-hoc Networks. Mobicom'99.

[9] J. Broch, D. Maltz, D. Johnson, Y-C. Hu and J. Jetcheva. A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols, Internet Draft.

[10] S.R. Das, R. Castaneda and J. Yan. Simulation Based Performance Evaluation of Routing Protocols for Mobile Ad Hoc Networks, ACM Baltzer Mobile Networks and Applications, 179-189, (5) 2000.

[11] E. Cayirci and C. Ersoy. Simulation of Tactical Communications Systems by Inferring Detailed Data from the Joint Theater Level Computer Aided Exercises, SIMULATION: Transactions of the Society for Modeling and Simulation, to appear.

[12] Y-C. Hu and D.B. Johnson. Caching Strategies in On-Demand Routing Protocols for Wireless Ad Hoc Networks, Internet Draft.