

Virtual Cellular Infrastructure For Mobile Ad hoc Network

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Abstract:

In this paper, we introduce a protocol which develops a dynamic infrastructure for wireless mobile ad hoc network. The architecture and operation of dynamic infrastructure is similar to conventional cellular network infrastructure. In this protocol, a mobile terminal (MT) is elected by a set of MTs to act as their temporary base station within their base station area based on residual battery power. MTs elected as base stations (BS) are used to track other MTs in the ad hoc network. The dynamic infrastructure routing protocol utilizes the mobility tracking mechanism to route packets from an MT to another MT in the network. This protocol is more efficient than any existing ad hoc routing protocols in terms of energy and load balancing. The infrastructure based ad hoc mobile network is less congested and fast converging to network topology change.

This scheme provides different medium access control, band width allocation policies and quality of service (QoS) guaranteed communication in ad hoc networks. It performs well in interactive and multimedia service in ad hoc network.

Index: Wireless mobile ad hoc network; dynamic infrastructure; ad hoc routing protocols; Performance evaluation.

1. Introduction

Mobile IP and wireless network supports mobility and broad range of services such as data, voice, image, and multimedia. But it restricts the true mobility in the networks. In this connection, one area which is getting much attention in past five years is wireless mobile ad hoc networks (MANET) [1, 2]. MANETs allows any time connectivity with complete absence of control and regulatory influences, whatsoever be the surroundings. The topology of ad hoc network may change with time as all or a set of MTs involved may move or adjust their transmission and reception parameters. An ad hoc wireless network eliminates the costs of infrastructure deployment. Ad hoc network can be deployed quickly to meet an immediate and specific application. Thus, such network is suitable in situations where there is no wireless communication infrastructure present or else the possibility of installing such infrastructure is nil. The limited energy and processing capability of MTs forming the network draws us to develop an energy efficient protocol. The unavailability of fixed infrastructure and the limited transmission range requires all the MTs in switched ON mode always. Moreover, sometimes it may be necessary for one MT to seek the aid of others in forwarding a packet to destination and hence overcoming the problem of transmission range. Developing a dynamic infrastructure for MANET is very important. Such an

infrastructure reduces the problems of mobile ad hoc network and simplifies routing, from a multi-hop, to a single-hop one, as in conventional cellular network. Dynamic infrastructure based network enables the use of widely used cellular protocols in ad hoc networks with simple variations. Such a dynamic infrastructure will form the basis for developing cellular routing protocols, which can provide different medium access control and QoS management. Therefore, an energy-conserving dynamic infrastructure and load balanced routing are developed for ad hoc networks.

In this paper, we propose a protocol for ad hoc networks, which establishes an energy conserving dynamic infrastructure, called virtual cellular infrastructure (VCI). Unlike WLAN, our scheme creates a completely independent mobile and dynamic infrastructure for ad hoc network. In VCI formation protocol, an MT is elected from a set of MTs to act as a temporary base station within its base station range. We also introduce a routing protocol for ad hoc networks, Cell based routing (CBR) protocol, which utilizes the VCI to route packets between nodes of the ad hoc network.

2. Related protocols

The routing issues, in a fixed infrastructure based network are different from routing in infrastructure less network, like ad hoc network. In ad hoc network each intermediate node between source and destination node acts as a router and topology of the network changes frequently. Therefore, routing protocols are crucial for proper functioning of ad hoc network. The available routing protocols can be classified as *table-driven* [3, 4], *on-demand* [4, 5, 6] and *hybrid routing protocols* [7]. In table-driven protocols each MT keeps routing information for all other MTs in the network. The routing table updates are sent periodically and/or on any change in topology across the network. This incurs significant routing overhead and unnecessary power drain at the MTs. For high density networks, the update message can be very large, this may saturate the network. Converging to new, stable route after dynamic changes in topology may be quite slow. This shortcoming of table-driven protocols often outweighs their advantages such as low route discovery latency compared to on-demand protocols.

In on-demand routing protocols, only route to the MTs to which a source needs to communicate are maintained by the source MT. In bandwidth limited ad hoc network, on-demand routing protocols are better suited because of their lower routing overhead. Two most popular on-demand routing protocols are Dynamic Source Routing (DSR) [8] and Ad hoc On-demand Vector routing (AODV) [9, 10] protocol. Most of

the on-demand protocols [5, 6] choose shortest path as their route selection criteria. This scheme of route selection leads to overloading of some of the MTs in the network. The performance of ad hoc network would improve when we consider the performance metrics such as packet delivery fraction and routing overheads, as mobility of the node is reduced. This may not be the case when we consider packet delay as the performance metrics. It was shown in ref. [11] that packet delay for both AODV and DSR increases as the mobility of MT is reduced.

One example for table-driven routing protocol is Cluster Gateway Switch Routing (CGSR) [12, 13, 14] protocols. It assumes the ad hoc network as hierarchical network. This protocol divides the ad hoc network into number of clusters, each having a set of MTs, which are at most two hops away. It is a logical arrangement of MTs in mobile ad hoc network with one MT at centre of the cluster. MT with highest connectivity is chosen to be the cluster head [18]. Each MT maintains the information about all the MTs in its cluster and all the cluster heads in the network. This information is periodically broadcasted in the network. Most of the existing protocols do not consider the load conditions in the network during the routing process. Associatively Based Routing (ABR) [15] in ad hoc network considers the routing load as the secondary performance metric. Routing with load balancing in wired infrastructure network has been exploited in ref. [16]. The reuse of existing cellular network infrastructure is beneficial to route packets in ad hoc network. Our proposed scheme ensures load balancing and power-aware routing [17].

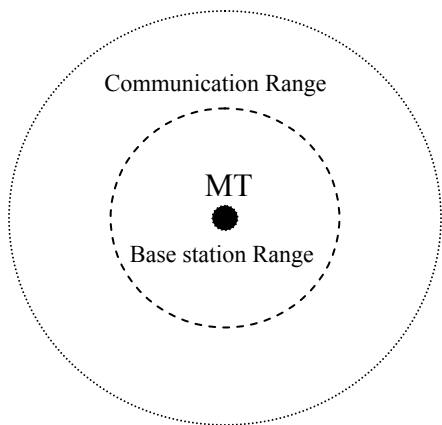


Fig. 1. Communication range and Base station range of an MT

3. VCI Formation protocols

We introduce a new dynamic infrastructure creation scheme to achieve energy conservation and load balancing in mobile ad hoc networks. The dynamic infrastructure is formed based on the residual battery power of the MTs

Every MT is assumed lying in the center of two imaginary concentric circles. Consider Fig.1, the area within the outer circle around MT is the Communication Range of MT. All MTs in this area can communicate with MT directly. The inner circle defines the base station range of MT (resembling the “cell” as in cellular network).

Each MT declares its existence by sending a “hello” messages periodically. The receiver of the “hello” message decides in which area it is located, based on the strength of the received radio signal. If the receiver can hear the signal, then it must be in communication range; and if the received radio signal is stronger than the value, called BS_Threshold, then receiver is within the sender’s base station range. With this dual-range method, we will be able create a dynamic infrastructure for ad hoc network similar to cellular network infrastructure, which also solve most of the problems caused by the limitations of ad-hoc networks. This dual range method ensures the tracking of MTs in a reliable way.

In our protocol, some of the MTs based on the residual battery power, will be selected as temporary BSs for all or a set of MTs in their base station range. This is achieved by electing one to be a BS by set of MTs. In ad hoc wireless networks, there are no fixed nodes available, nodes move randomly and are not permanently switched on, besides there are no wired connections. Hence, compared to a fixed cellular network, BSs are also mobile and temporarily available. If a BS moves or stops acknowledging its presence via its periodic “hello” messages, for a period of time, a new BS is elected. Electing a single BS from a set of nominees is done in an efficient way. All MTs have My_BS_IP variable which is used to store the IP address of the BS in charge of that MT. If an MT is under a BS, its My_BS_IP variable will be set to IP address of that BS, else if the MT is itself a BS, then the My_BS_IP variable will be set to 1, otherwise it will be set to 0. In addition to My_BS_IP, My_BP variable is used to indicate its battery power.

An MT is chosen by one or more MTs, to act as their BS based on power threshold. MTs broadcast “hello” message periodically. The “hello” message contains IP address of MT, My_BP, BP_Threshold_flag, BS_Threshold and other useful information.

BP_Threshold_flag is used by the BSs to convey the MTs it is currently in charge of, whether it can support them for another hello period or not. This flag will be set to 1 when the battery power of BS reaches below the BP_Threshold. If this flag is set to 0, the MTs under the BS know that they will be still served by their BS for another hello period, and therefore do not need to look for a new BS for at least one more hello period. However, if that flag is set by the BS to 1, then the MTs will be relieved from the BS and a new BS will be elected.

BS_Threshold is used by a BS to control its base station area. BS_Threshold is the radio signal strength at the edge of base station area. BS sets a value for this variable depending on its load, so that BS can control the number of MTs registered under it.

An MT sends a registration-request message to another MT if the latter has a My_BP value greater than the former and received radio signal strength is above the BS_Threshold. Receiver of registration-request message responds positively only if its My_BP is above the BP_Threshold, at the time it receives the registration-request message, in this case it sets its My_BS_IP variable to 1, and replays with accept-registration message. The receiver of accept-registration message sets its My_BS_IP variable to the IP address of its new BS. If an MT hears from another MT

whose My_BP value is greater than that of its current BS, it sends a registration-request message to former. If it gets accept-registration message, it sets its My_BS_IP to IP address of new BS and it sends a un-register message and IP address of new BS to old BS. If the BS receives the un-register message, it stores the sender's information for a small period of time. If radio signal strength received by an MT from its BS is below the BS_threshold for some timeout period, it looks for new BS. When this MT re-registers with a new BS, it may be still within the communication range of the previous BS, and can hence inform the old BS of its new registration.

4. Cell based routing

The cell based routing (CBR) protocol utilizes the VCI creation protocol to route packets from one MT to another MT in ad hoc network. CBR is similar to routing in conventional fixed cellular network and solves most of the problem of routing in ad hoc networks.

All MTs run the VCI creation protocol, and some of the MTs are elected to act as BS for set of terminals in their cells. In such infrastructure based ad hoc network all the MTs relies on the dynamic infrastructure to communicate with other MTs. Each and every BS is in charge of a set of MTs in their cell including itself. In CBR only BSs that form dynamic infrastructure are eligible to acquiring the knowledge of full network topology. Route requests are not flooded to the rest of the network due to the existence of the dynamic infrastructure.

As in conventional cellular network, when an MT wishes to send a packet it sends it to its BS. BS forwards the packet directly to the BS in charge of the destination MT, if they are in communication range. Otherwise, the source BS seeks aid of intermediate BSs to route packets to destination MT. When the BS receives the packet, it looks up the destination address in its table. If the destination BS is found in the communication range, it will forward the packet to the BS in charge of the destination. If destination BS is out of range, the packet is then forwarded to one intermediate BS whose IP address is stored in the BS field. After receiving the packet, intermediate BS forwards it to next BS if it is not in communication range of destination BS. This process is repeated until the packet reaches the destination. Path maintenance is an on-the-fly, built-in process. MTs under BSs are not used to route packet between two other MTs, this eliminates routing load from low power MTs.

Apparently, MTs are neither responsible for the burden of discovering new routes, nor maintaining existing ones. Hence, CBR scheme eliminates the route search latency, introduced by the discovery phase in on-demand routing protocols, which degrades the performance in interactive and multimedia applications.

5 Performance evaluations

In this section, we study the performance of VCI formation scheme and CBR protocol with the help of simulation experiment. CGSR protocol assumes a hierarchical

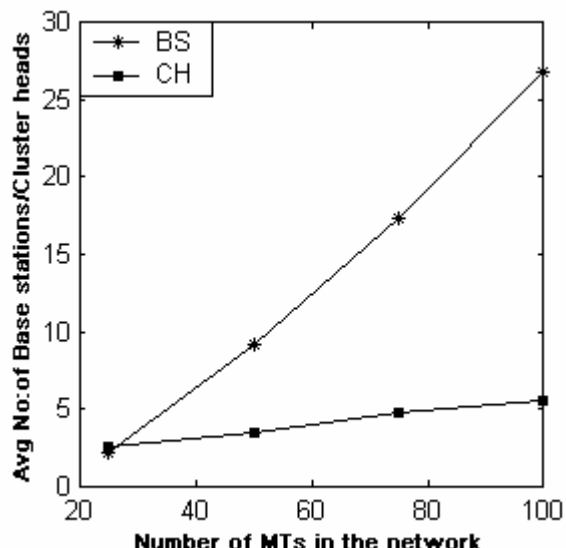


Fig . 2. Effect of network density on number of base stations

network to route the packet in ad hoc network. Since VCI forms a similar hierarchical network, the performance of dynamic infrastructure of both can be compared. Again, since AODV and DSR are two popular routing protocols, performance of CBR protocol is compared with AODV and DSR. The section 5.1 describes the simulation model. A description of the performance metrics that were taken into account for evaluating the performances are given in the section 5.2. The results of the conducted simulation experiments are presented in Section 5.3.

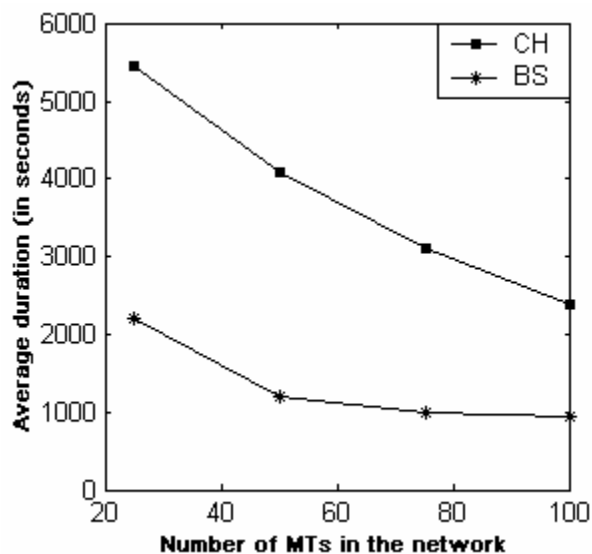


Fig . 3. Effect of network density on duration of base stations

5.1 Simulation model

A discrete-time simulator was developed using the programming language JAVA. Simulation experiment was conducted to analyze the performance of VCI formation scheme and CBR protocol. Ad hoc networks with different node densities and pause times were simulated. The simulated

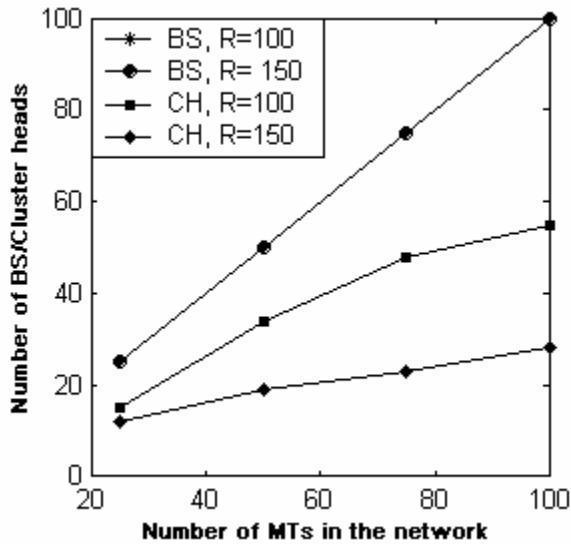


Fig. 4. Effect of network density on total number of base stations elected

ad hoc network had a bit rate of 2 Mb/s. The MTs are equipped with 100 m radio transmission range transceivers using omnidirectional antenna. MTs broadcast “hello” messages in every 0.1s. The maximum allowed retransmissions for any packet is 2, and a packet is retransmitted 0.2 s later. The MTs are distributed randomly in the simulation area. The MTs roam freely in random fashion within the simulation area. The routing protocol will be initiated whenever an MT transmits or receives a packet. The run-time of simulation experiments are adjusted for 900 s. Initial battery powers of MTs is randomly selected between the maximum possible and the threshold value.

Traffic models

We have chosen constant bit rate data traffic sources. We have simulated ad hoc network with different number of traffic sources to vary the traffic load in the network. More the traffic sources more will be the number of packets to be routed by the network. The traffic sources and destinations are distributed randomly over the simulation area and roams randomly when it transmits data packets. Each MT generates packet at a rate of 4 packets/sec. When an MT receives a packet addressed to it, it sends back an acknowledgment to confirm the reception of the packet.

Mobility model

In the simulation, each MT moves in a random fashion. Every MT can either be in moving state or in stable state. In the moving state the speed of the MTs is uniformly distributed between 1 and 25m/s. Mobility is varied by means of varying the pause/rest period. Smaller the pause period, higher the mobility and, vice versa. This means that varying the duration of the pause period is equivalent to varying the mobility of the terminals. Each and every MT alternately rests and moves to a new random location within the simulation area. Experiments were conducted for different pause periods. It was also

possible to vary the mobility by changing the velocities of MTs movement.

5.2 Performance metrics

The following are the performance metrics we considered for evaluation.

1. *Average number of BSs*: This is the average number of base station formed in each simulation run. Smaller number of base station indicates large number of MTs under each base station and vice versa.
2. *Average BS duration*: This is the average time duration for which a MT remains as a BS in the simulation run-time. It is a measure of network stability; larger the duration, the more stable the infrastructure and vice versa. Too large duration means load is concentrated on same base station. Results in quick lose of battery power.
3. *Total number of MTs elected as BS*: Total number of MTs served as BSs during the whole simulation run-time. This metric indicates possibility of re-election of same MT as BS. Small value of this implies that a small fraction of MTs is elected as BSs.
4. *Packet delivery fraction*: This is the ratio of data packets delivered to destination addresses to those generated by the traffic sources in a simulation run. Larger value of this parameter implies low packet loss probability and more reliability of routing protocol.
5. *Normalized routing load*: This is the number of routing packets generated per data packet delivered at the destination address. Smaller the value of normalized routing load, end-to-end delay is small. This means that the routing protocol provides reliability and overhead-free communications.

5.3 Simulation result

The simulation of VCI formation scheme develops more number of BS in the same area. The more number of BS is due to the selection method of BS, a BS is elected based on the power threshold, so the load is distributed on all base stations. CGSR produce small number of cluster heads (CH), since only one cluster head exist in a cluster. In CGSR the MT with high connectivity is selected as CH [18], therefore, load is concentrated on small number of MTs, which exhaust battery power quickly. Fig. 2 shows number of BSs formed for different number of MTs. Number of BSs increases linearly as the number of MTs increases. In the case of CGSR, number of CH is almost constant. Hence, VCI formation scheme ensures load balancing.

The fig. 3 shows the average BS and CH duration for different number of MTs in the network. The average duration measures the stability of the hierarchical architecture. Since CHs are selected based on the MT connectivity, same MT will act as CH for longer duration. This will exhaust CHs battery power and the network may fall short. In VCI formation scheme MT act as BS up to its power reduces below the power threshold, then a new BS will be selected. It provides stable and energy efficient cellular architecture. The stability comes from the fact that, when a MT moves, it will either remain under the supervision of same BS or will join with another BS immediately.

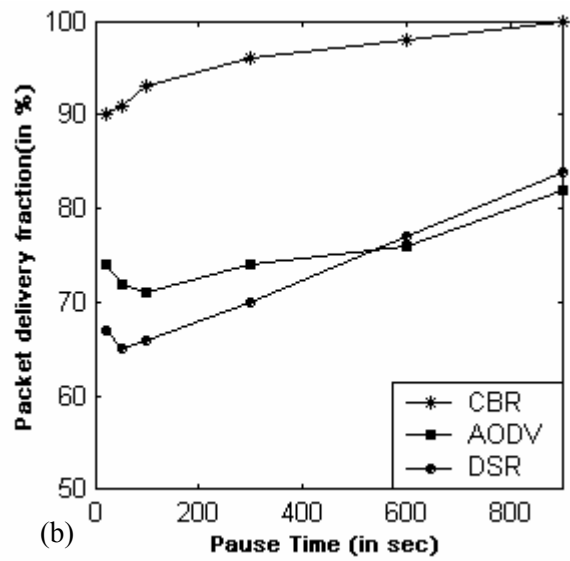
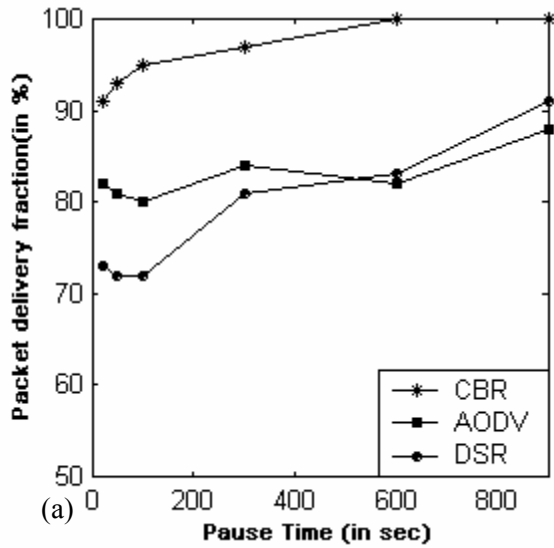


Fig . 5. Packet delivery fraction for 50 MTs model (a) 30 traffic source; (b) 25 traffic source

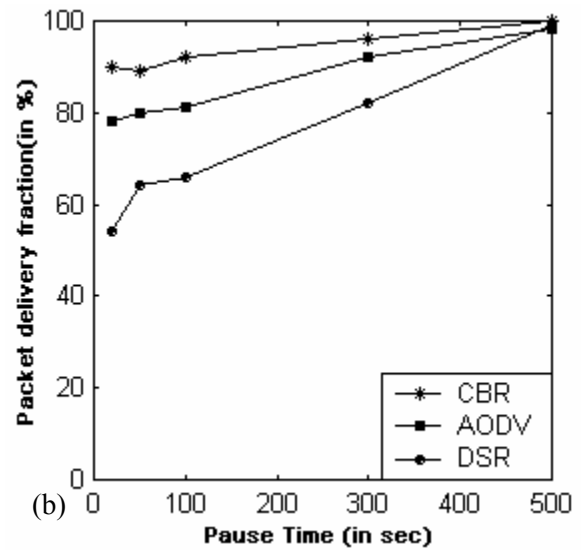
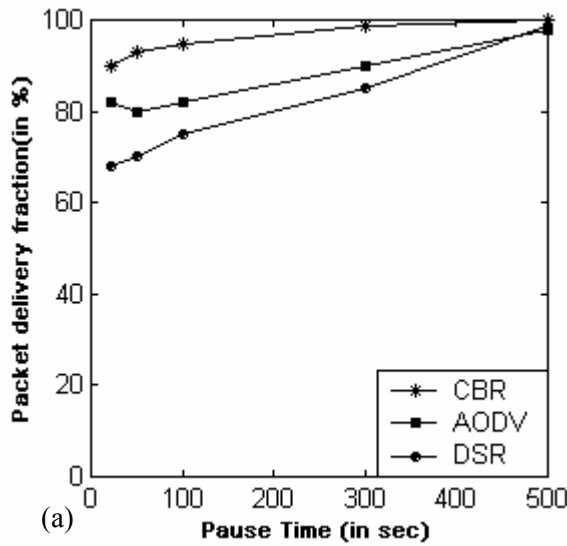


Fig . 6. Packet delivery fraction for 100 MTs model (a) 30 traffic source; (b) 25 traffic source

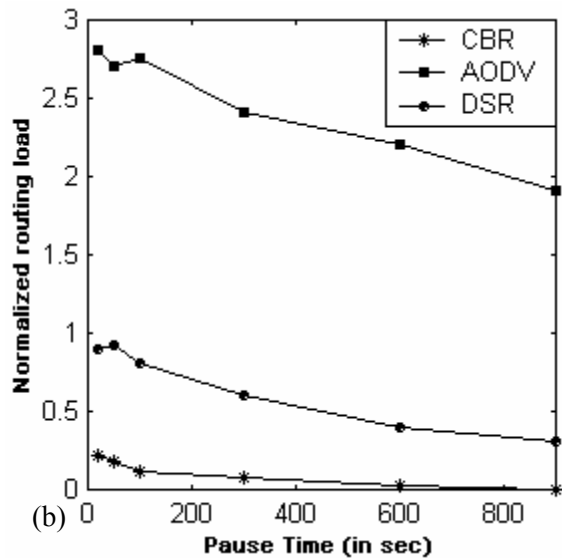
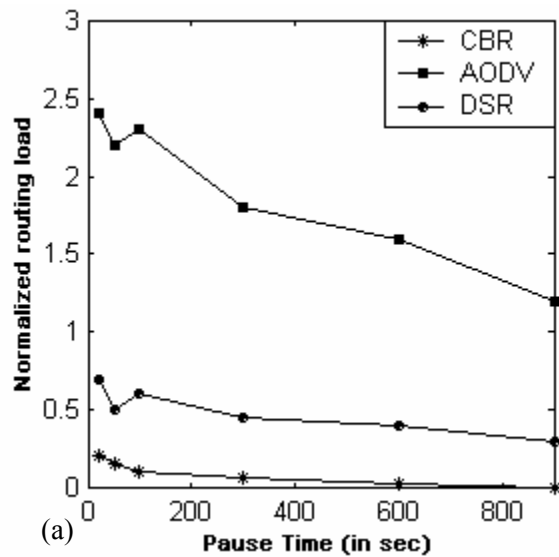


Fig . 7. Normalized routing load for 50 MTs model (a) 30 traffic source; (b) 25 traffic source

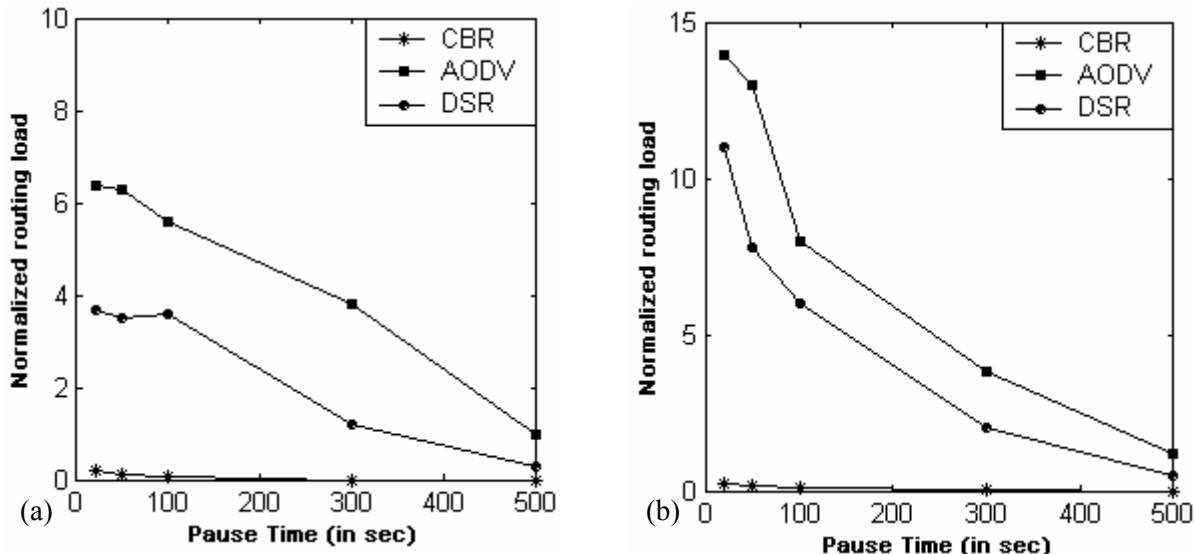


Fig. 8. Normalized routing load for 100 MTs model (a) 30 traffic source; (b) 25 traffic source

Fig. 4 shows the load balancing property of VCI formation scheme. Since all the MTs are elected as BSs at least once during the simulation run-time, load is shared by all the MTs in the network. In the case of CGSR, only small fraction of total number of MTs is elected as CHs during the run-time. This implies that load is concentrated on smaller number of MTs participated in the ad hoc network. Fraction of total number of MTs elected as CHs decreases as wireless communication range (R) increases. In contrast, VCI formation scheme has no effect on wireless communication range.

For evaluating the performance of CBR protocol, the simulation experiment was performed with varying number of MTs and traffic source. Fig. 5 shows simulation result of 50 mobile terminals in the network with 25 and 35 traffic sources. Fig. 5(a) shows packet delivery fraction (PDF) with 25 traffic source model for different value of pause period, and it compares CBR protocol with AODV and DSR. Figure shows excellence of CBR protocol, it achieves more than 25% PDF compared with AODV and DSR. This improvement in performance is due to absence of route discovery and route maintenance process in CBR. The routing information stored in the BSs reduces the routing packet to transfer the data packet. CBR shows low packet loss probability and is more reliable. Fig. 5(b) shows packet delivery fraction for 35 traffic source model, where CBR have roughly 30% more PDF compared with AODV and DSR.

Fig. 6 uses 100 MTs model with 25 and 35 traffic sources respectively. CBR reports greater PDF compared with AODV and DSR. In both cases CBR provides more delivery, then AODV and DSR. Thus, it is more reliable even under high load conditions and varying node densities. PDF of CBR improves when number of MTs in the network increases. VCI scheme provides more stable infrastructure for large number of MTs. This improves the PDF of CBR. In case of AODV and DSR no significant improvement in PDF is felt for large number of MTs. CBR outperforms AODV and DSR in terms of routing load.

Fig. 7 shows the normalized routing load for variation of pause time for 50 MTs model with 25 and 35 traffic sources. In fig. 7(a), CBR have very low value of routing load. AODV shows high value of routing load then DSR. In these protocols route discovery phase will be initiated for any link failure. This adds more over head on the routing packets. In CBR, MTs do not initiate route discovery or store routing to any other MTs in the network. The BSs forward the packets to destination BS. Since most of the base stations are in communication range re-transmissions are rarely required. Fig. 7(b) shows normalized routing loads for same variation of pause time with 35 traffic sources. Even for high mobility and traffic, CBR shows low routing load.

For high density network AODV and DSR produce more route request broadcast message and route reply message. Each MT has much number of neighbours and route request is forwarded to each of them. Each neighbour also produce route request message. This produces more route reply and hence increases the routing load. Fig. 8 shows the normalized routing load for 100 MTs with 25 and 35 traffic sources. As the mobility increases, the performance of both AODV and DSR reduces. Therefore, for high mobility and high density network AODV and DSR are not apt. In VCI, as the network density increases only few more base stations will be selected, each of which acquire network topology and will participate in the routing process with out increasing routing load. The CBR produces very low routing load, since each base station have the complete knowledge of network topology.

6 Conclusions

The available routing protocols for mobile ad hoc network satisfy only some of the requirements. Some of the popular routing protocols have been discussed in [3,4]. AODV and DSR do not consider the load during route recovery process. They search for shortest route which may highly overload some of the MTs in the network leading to fast battery exhaustion and high end to end delay. For high density network AODV and DSR broadcast more route request and

reply messages, producing more congestion. None of the available routing protocols consider load as the primary performance metric. We have introduced a dynamic infrastructure formation protocol, VCI formation protocol, which develops a dynamic infrastructure similar to conventional cellular network infrastructure. We have also introduced a routing protocol, CBR, similar to cellular network routing protocol. The CBR protocol uses VCI to route packets in the network.

CBR protocol is a hybrid routing protocols. Unlike table-driven routing protocols, only base stations need to keep network topology, and unlike on-demand routing protocols, routes between MTs of ad hoc network are not build only based on request from source node. In CBR protocol, when an MT desires to send packet to another MT in the network, it does that by forwarding the same to its BS. It sends the packet of information to destination address, only if the destination is one of the registered MT with it. If the destination is found in any other BS, source BS forwards the packet to BS in charge of destination MT. We have compared our protocols with AODV and DSR, and found that it outperforms in terms of packet delivery fraction and routing load. Our simulation experiment proved VCI elects all the MTs as BS, i.e., all nodes will serve as BS, at least once, during their session period. VCI keeps total consumed energy by the MTs almost constant. This assures fair energy consumption amongst the MTs. VCI balances load amongst the MTs regardless of the carried routing load. The CBR protocol provides different channel access scheme, band-width allocation policies and quality of service (QoS) guaranteed communication in wireless mobile ad hoc networks. It performs well in interactive and multimedia service in ad hoc network.

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