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DISTRIBUTED ADAPTIVE ROUTING IN WIRELESS ADHOC NETWORKS

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Abstract:- An ad-hoc network of wireless static nodes is considered as it arises in a rapidly deployed, sensor based, monitoring system. Information is generated in certain nodes and needs to reach some designated gateway node. Each node may adjust its power within a certain range that determines the set of possible one hop away neighbours. Traffic forwarding through multiple hops is employed when the intended destination is not within immediate reach. The nodes have limited initial amounts of energy that are consumed in different rates depending on the power level and the intended receiver.

But, in practice this is difficult to achieve since existing protocols do not provide accurate power information and do not exploit these savings in a mobile environment. A distributed adaptive opportunistic routing scheme for multi hop wireless ad-hoc networks is proposed. The proposed scheme utilizes a reinforcement learning framework to opportunistically route the packets even in the absence of reliable knowledge about channel statistics and network model. This scheme is shown to be optimal with respect to an expected average per packet reward criterion. The proposed routing scheme jointly addresses the issues of learning and routing in an opportunistic context, where the network structure is characterized by the transmission success probabilities. In addition, the proposed routing protocol works on the basis of a virtual cluster, consisting of a collection of only those nodes that are one-hop distance away. The idea is to significantly reduce the control overheads such as route query packets as well as the flooding time for collecting the network topology information at a destination. The key feature of the proposed scheme is that it draws on short packet transfer delay of PRP (Proactive Routing Protocol) and the small control overheads performance of RRP (Reactive Routing Protocol). A backup route is intended to further improve the delay performance. A disconnected route can be replaced by backup route, if available. No additional computational overheads are increased for computing the backup route. The idea is to significantly reduce the control overheads such as route query packets as well as the flooding time for collecting the network topology information at a destination. The key feature of the proposed scheme is that it draws on short packet transfer delay of PRP (Proactive Routing Protocol) and the small control overheads performance of RRP (Reactive Routing Protocol).

Keywords:— wireless ad-hoc networks, Proactive Routing Protocol, Reactive Routing Protocol, hop, multi-hop, flooding.

I. INTRODUCTION

On wireless computer networks, ad-hoc mode is a method for wireless devices to directly communicate with each other. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points (including those built in to broadband wireless routers).An ad-hoc network tends to feature a small group of devices all in very close proximity to each other. Performance suffers as the number of devices grows, and a large ad-hoc network quickly becomes difficult to manage. Ad-hoc networks cannot bridge to wired LANs or to the Internet without installing a special-purpose gateway. Ad hoc networks make sense when needing to build a small, all-wireless LAN quickly and spend the minimum amount of money on equipment. Ad hoc networks also work well as a temporary fallback mechanism if normally-available infrastructure mode gear (access points or routers) stop functioning.

A wireless ad hoc network is a decentralized type of wireless network. The network is ad hoc because it does not rely on a pre existing infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity. In addition to the classic routing, ad hoc networks can use flooding for forwarding data. An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network device in link range. Ad hoc network often refers to a mode of operation of IEEE 802.11 wireless networks.

Routing is the process of selecting best paths in a network. In the past, the term routing was also used to mean forwarding network traffic among networks. Routing is performed for many kinds of networks, including the telephone network (circuit switching), electronic data networks (such as the Internet), and transportation networks. This thesis is concerned primarily with routing in electronic data networks using packet switching technology. Dynamic Routing describes the capability of a system, through which routes are characterized by their destination, to alter the path that the route takes through the system in response to a change in conditions. The adaptation is intended to allow as many routes as possible to remain valid (that is, have destinations that can be reached) in response to the change.

Multi-hop routing: No default router available, every node acts as a router and forwards each other's packets to enable information sharing between mobile hosts.

In this paper we propose a new reactive Opportunistic based distributed routing protocol, which can be interpreted as an extension to the multi-hop Ad Hoc On Demand Distance Vector Routing (AODV) algorithm. An Opportunistic based distributed routing is a form of cooperative transmission (CT) in which a group of simple, inexpensive relays or forwarding nodes operate without any mutual coordination, but naturally fire together in response to energy received from a single source or another Opportunistic based distributed routing. An Opportunistic based distributed routing transmission has the same model as a multi-path signal with delay and Doppler spreads, and therefore can be successfully decoded by receivers designed to tolerate the spreads.

In contrast, the proposed routing protocol avoids these scalability problems, because no nodes are individually addressed (aside from the Source and Destination Nodes) and the complexity of the proposed scheme is independent of node density.

The Proposed reactive routing protocols, such as AODV and DSR, our algorithm involves mainly three phases: (1) Route Request (RREQ) broadcast by the Source Node Route Reply (RREP) Unicast by Destination Node and (3) Unicast data transmission (DATA).

We investigate the problem of opportunistically routing packets in a wireless multi-hop network when zero or erroneous knowledge of transmission success probabilities and network topology is available. Using a reinforcement learning framework, we propose an adaptive opportunistic routing algorithm which minimizes the expected average per packet cost for routing a packet from a source node to a destination.

The opportunistic algorithms proposed and implicitly depend on a precise probabilistic model of wireless connections and local topology of the network. In practical setting, however, these probabilistic models have to be "learned" and "maintained". The question of estimation error and learning in the opportunistic routing context has recently received some attention. In this paper, using a reinforcement learning framework, we propose a distributed Adaptive Opportunistic Routing (d-AdaptOR) algorithm which minimizes the expected average per packet cost when zero or erroneous knowledge of transmission success probabilities and network topology is available.

This algorithm extends our earlier centralized algorithm to allow for a practical distributed asynchronous implementation with low complexity and overhead costs.

The most significant characteristics of the proposed scheme are:-

1) it does not assume any initial knowledge of the network,
2) it is distributed, and
3) it is asynchronous,

i.e. it only requires a local clock at each node.

II. SYSTEM MODEL

We consider the problem of routing packets from the source node o to a destination node d in a wireless ad-hoc network of d + 1 nodes denoted by the set _ = fo; 1; 2; _ _ _ ; dg. The time is slotted and indexed by n _ 0 (this assumption is not technically critical and is only assumed for ease of exposition).A packet indexed by m _ 0 is generated at the source node o at time _m s according to an arbitrary distribution with mean_ > 0.

Given a successful transmission from node i to the set of nodes S, the next (possibly randomized) routing decision includes 1) retransmission by node i, 2) relaying the packet by a node j 2 S, or 3) dropping the packet all together. If node j is selected as a relay, then it transmits the packet at the next slot, while other nodes k 6= j; k 2 S, expunge that packet.

We assume upon a transmission from node i, a fixed transmission cost c_i > 0 is incurred. Transmission cost c_i can be considered to model the amount of energy used for transmission, the expected time to transmit a given packet, or the hop count when the cost is equal to unity.

We define the termination event for packet m to be the event that packet m is either received by the destination or is dropped by a relay before reaching the destination. We define termination time _m e to be a random variable when packet m is terminated. We discriminate amongst the termination events as follows: We assume that upon the termination of a packet at the destination (successful delivery of a packet to the destination), a fixed and given positive reward R is obtained, while if the packet is terminated (dropped) before it reaches the destination, no reward is obtained. Let $i_{n,m}$ denote the random reward obtained at the termination time _m e , i.e. it is either zero if the packet is dropped prior to reaching the destination node or R if the packet is received at the destination. Let $i_{n.m}$ denote the index of the node which transmits packet m at time n. The routing scheme can be viewed as selecting a (random) sequence of nodes $\{i_{n,m}\}$ for relaying packets m = 1; 2; _ _ _ . As such, the expected average per packet reward associated with routing packets along a sequence of $\{i_{n,m}\}$ up to time N is:

$$J_N = \mathbf{E}\left[\frac{1}{M_N}\sum_{m=1}^{M_N}\left\{r_m - \sum_{n=\tau_s^m}^{\tau_e^m - 1} c_{i_{n,m}}\right\}\right],$$

Where M_N denotes the number of packets terminated upto time N and the expectation is taken over the events of transmission decisions, successful packet receptions, and packet generation times.

Problem (P) Choose a sequence of relay nodes $\{i_{n.m}\}$ in the absence of knowledge about the network topology such that J_N is maximized as $N \to \infty$. In the next section we propose d-AdaptOR algorithm which solves.

Problem (P). The nature of the algorithm allows for nodes to make routing decisions in distributed, asynchronous, and adaptive manner.

Remark :- The problem of shortest path routing between all source-destination pairs can be effectively decomposed to the problem above where routing from one node to a specific destination is addressed.

III. DISTRIBUTED ALGORITHM

In this section we present an overview and detailed description of the proposed distributed adaptive opportunistic routing (d-AdaptOR) algorithm. In the rest of the paper, we let N(i) to denote the set of neighbors of node i including node i itself. Let Si be the set of potential reception outcomes due to transmission from node $i \in \Theta$, i.e. $\mathfrak{S}^i = \{S : S \subseteq \mathcal{N}(i), i \in S\}$. For all $S \in \mathfrak{S}^i$, let A(S) denote all the potential routing decisions (actions) for node i. A(S) includes the set of nodes S and the termination action f, i.e. $A(S) = S \cup \{f\}$

Furthermore, for each node i we define a reward function on states S ∈ Si and potential decisions a ∈ A(S) as:

$$g(S,a) = \begin{cases} -c_a & \text{if } a \in S \\ R & \text{if } a = f \text{ and } d \in S \\ 0 & \text{if } a = f \text{ and } d \notin S \end{cases} .$$

A. Overview of d-AdaptOR

As discussed before, the routing decision at any given time is made based on the successful outcomes and involves retransmission, choice of next relay, or termination. Our proposed scheme makes such decisions in a distributed manner via the following three-way handshake between a node i and its neighbors N (i).

1) At time n node i transmits a packet.

2) Set of nodes S_n^i that have received the packet successfully from node i, transmit acknowledgment packets to node i. The acknowledgment packet of node $k \in S_n^i$ includes node's identity and a message summarizing its estimated best score (EBS) denoted by Λ_{max}^k.

3)Node i announces node $j \in S_n^i$ as the next transmitter or announces the termination decision f.

The routing decision of node i at time n is based on an adaptive (stored) score vector $\Lambda_n(i,\cdot,\cdot)$. The score vector $\Lambda_n(i,\cdot,\cdot)$ lies in space $\mathbb{R}^{v_i}$, where $v_i = \sum_{S \in \mathfrak{S}^i} |A(S)|$ and is updated by node i using the EBS messages Λ_{max}^k obtained from neighbors $k \in S_n^i$ Furthermore, node i uses a set of counting variables $\nu_n(i,S,a)$ and $N_n(i,S)$ and a sequence of positive scalers $\{\alpha_n\}_{n=1}^{\infty}$ to update the score vector at time n. The counting variable $\nu_n(i,S,a)$ is equal to the number of times set of nodes S have received the packet and decision a has been taken due to transmission from node i up to time n, while $N_n(i,S)$ is equal to the number of times set of nodes S have received the packet due to transmission from node i up to time n. Lastly, $\{\alpha_n\}_{n=1}^{\infty}$ is a fixed sequence of numbers available at all nodes.

The details are presented next.

B. Detailed description of d-AdaptOR

The operation of d-AdaptOR can be described in terms of initialization and four stages of transmission, reception and acknowledgment, relay, and adaptive computation as shown in Figure 1. For simplicity of presentation we assume a sequential timing for each of the stages. We use n+ to denote some (small) time after the start of nth slot and (n + 1)− to denote some (small) time before the end of nth slot such that n < n+ < (n + 1)− < n + 1.

<u>0)Initialization:-</u>

For all $i \in \Theta, S \in \mathfrak{S}^i, a \in A(S)$), initialize $\Lambda_0(i,S,a) = 0,\ \nu_0(i,S,a) = 0,\ N_0(i,S) = 0,\ \Lambda_{max}^f = -R, \Lambda_{max}^i = 0.$

<u>1)Transmission Stage: -</u>

Transmission stage occurs at time n in which node i transmits if it has a packet.

2)<u>Reception and Acknowledgment Stage:-</u>

Let S_n^i denote the (random) set of nodes that have received the packet transmitted by node i. In the reception.

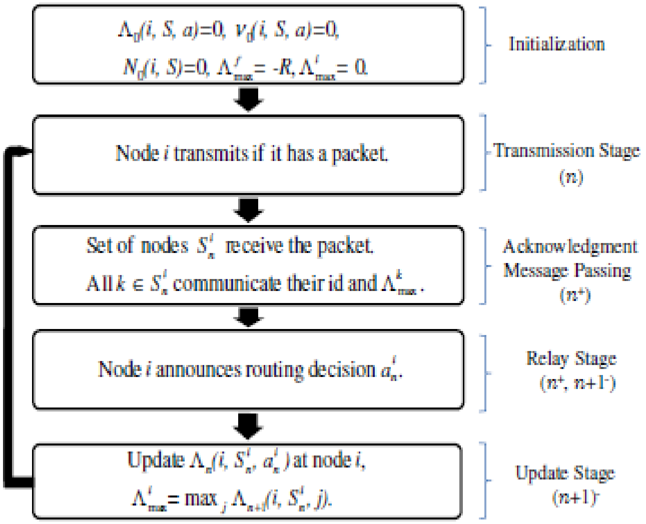

Fig. 1. Flow of the algorithm. The algorithm follows a four-stage procedure: transmission, acknowledgment, relay, and update. In the acknowledgment stage, a node obtains Λ^k_{max}. from the neighbors (message passing).

and acknowledgment stage, successful reception of the packet transmitted by node i is acknowledged to it by all the nodes in Sin. We assume that the delay for the acknowledgment stage is small enough (not more than the duration of the time slot) such that node i infers S^i_n

by time n+.

For all nodes $k \in S^i_n$, the ACK packet of node k to node i includes the EBS message Λ^k_{max}. Upon reception and acknowledgment, the counting random variable Nn is incremented as follows:

$$N_n(i,S) = \begin{cases} N_{n-1}(i,S)+1 & \text{if } S = S^i_n \\ N_{n-1}(i,S) & \text{if } S \neq S^i_n \end{cases}$$

3)<u>Relay Stage:</u>

Node i selects a routing action $a^i_n \in A(S^i_n)$ according to the following (randomized) rule:

- with probability $(1 - \epsilon_n(i, S^i_n))$,

$$a^i_n \in \arg\max_{j \in A(S^i_n)} \Lambda_n(i, S^i_n, j)$$ is selected

- with probability $\frac{\epsilon_n(i,S^i_n)}{|A(S^i_n)|}$, $a^i_n \in A(S^i_n)$ is selected randomly.

$$\epsilon_n(i,S) = \frac{1}{N_n(i,S)+1}.$$

Where

Node i transmits a control packet which contains information about routing decision ain at some time strictly between n+ and (n + 1)−. If ain 6= f, then node ain prepares for forwarding $j \in S^i_n, j \neq a^i_n$ in next time slot while nodes. expunge the packet. If termination action is chosen, i.e. $a^i_n = f,$ all nodes in S^i_n expunge the packet.

Upon selection of routing action, the counting variable ν_n is updated.

$$\nu_n(i,S,a) = \begin{cases} \nu_{n-1}(i,S,a)+1 & \text{if } (S,a) = (S^i_n, a^i_n) \\ \nu_{n-1}(i,S,a) & \text{if } (S,a) \neq (S^i_n, a^i_n) \end{cases}$$

.

4)Adaptive Computation Stage:

At time (n + 1)−, after being done with transmission and relaying, node i updates score vector $\Lambda_n(i,\cdot,\cdot)$ as follows:

- for $S = S^i_n,\ a = a^i_n,$

$$\Lambda_{n+1}(i,S,a) = \Lambda_n(i,S,a) + \alpha_{\nu_n(i,S,a)} \Big(- \Lambda_n(i,S,a) + g(S,a) + \Lambda^a_{max} \Big),$$

- otherwise, $\Lambda_{n+1}(i,S,a) = \Lambda_n(i,S,a).$

Furthermore, node i updates its EBS message Λ^i_{max} for future acknowledgments as:

$$\Lambda^i_{max} = \max_{j \in A(S^i_n)} \Lambda_{n+1}(i, S^i_n, j).$$

IV. OPTIMALITY OF D-ADAPTOR

We will now state the main result establishing the optimality of the proposed d-AdaptOR algorithm under a time-invariant model of packet reception. Let us characterize the behaviour of the wireless channel using a probabilistic local broadcast model. The local broadcast model is defined using the transition probability $P(S|i), S \subseteq \Theta, i \in \Theta$, where $P(S|i)$ denotes the probability of successful reception of packet transmitted by node i by all the nodes in S. Note that for all $S \neq S'$, successful reception at S and $S'$are mutually exclusive and $\sum_{S \subseteq \Theta} P(S|i) = 1$ Furthermore, we assume that successful transmissions over different time slots are independent and identically distributed.

The proposed local broadcast model is assumed to truly capture the coupling of the physical layer and the media access control (MAC) layer. In other words, the local broadcast model takes into account signal degradation due to path loss and multipath fading as well as captures the interference produced by other transmitting nodes. Note that, our model together with Assumption 1 imply an underlying MAC whose operation is controlled at a distinct layer and independently of the routing decisions. Furthermore, the implicit existence of a MAC scheme allows for a set of more advanced MAC schemes. Finally, the identically distributed assumption on successful transmissions imposes a time-homogeneity on the operation of the network and significantly restricts the topology changes of the network. In Sections V and VII, we address the severity and implications of the above consequences of Assumption 1. In particular, we will show that d-AdaptOR exhibits many of its desirable properties and performance improvements in practice despite relaxation of the analytical assumptions.

Let P be the sample space of the random probability measures for the local broadcast model. Specifically, P := { $p \in \mathbb{R}^{2^d} \times \mathbb{R}^d$: is a non-square left stochastic matrix }. Moreover, let $\mathcal{P}_P$ be the trivial - field generated by the local broadcast model P 2 P (sample point in P), i.e $\mathcal{P}_P = \{P, \mathbb{P} \backslash P, \emptyset, \mathbb{P}\}$.[3] Let S_n^i be the set of nodes that have received the packet due to transmission from node i at time n, while a_n^i denotes the corresponding routing decision node i takes at time n.[4] A distributed routing policy is a collection $\phi = \{\phi^i\}_{i \in \Theta}$ of routing decisions taken at nodes $i \in \Theta$,where ϕ^i denotes a sequence of random actions $\phi^i = \{a_0^i, a_1^i, \ldots\}$ for node i. The policy is said to be admissible if for all nodes $i \in \Theta, S \in \mathfrak{S}^i, a \in A(S$, , the event $\{a_n^i = a\}$ belongs to the - field $\mathcal{H}_n^i$ generated by the observations at node i, i.e. $\bigcup_{j \in \mathcal{N}(i)} \{S_0^j, a_0^j, \ldots, S_{n-1}^j, a_{n-1}^j, S_n^j\}$. Let denote the set of such admissible policies. These policies are implementable in a distributed manner under the following assumption.

Assumption 2. The successful reception at set S due to transmission from node i is acknowledged perfectly to node i. With the above notations and assumptions, the following theorem establishes the optimality of d-AdaptOR, i.e. d-AdaptOR denoted by, maximizes the expected average per packet reward obtained in (1) as $N \to \infty$.

Theorem 1. Suppose $\sum_{n=0}^{\infty} \alpha_n = \infty$, $\sum_{n=0}^{\infty} \alpha_n^2 < \infty$, *and Assumptions 1 and 2 hold. Then for all* $\phi \in \Phi$,

$$\lim_{N \to \infty} E^{\phi^*} \left[\frac{1}{M_N} \sum_{m=1}^{M_N} \left\{ r_m - \sum_{n=\tau_s^m}^{\tau_e^m - 1} c_{i_n,m} \right\} \right]$$
$$\geq \limsup_{N \to \infty} E^{\phi} \left[\frac{1}{M_N} \sum_{m=1}^{M_N} \left\{ r_m - \sum_{n=\tau_s^m}^{\tau_e^m - 1} c_{i_n,m} \right\} \right]$$

where E__ and E_ are the expectations taken with respect to policies __ and _ respectively.5Next we prove the optimality of d-Adapt OR in two steps. In the first step, we show that _n converges in an almost sure sense. In the second step we use this convergence result to show that d-Adapt OR is optimal for Problem (P).Lowest-numbered identifier in its uncovered neighbors, where any node that has not yet elected its master is said to be uncovered. Fig. 3(a) shows the process of master selection based on this algorithm. Nodes 1 and 4 elect themselves as masters and nodes 2 and 3 are covered by those masters. Among uncovered nodes (nodes 5, 6 and 7), node 5 elect itself as a master because it has the lowest identifier. By definition, a master node cannot have another master as a neighboring node and thus, this algorithm produces an single-gateway structure..

V. ANALYSIS RESULTS

We evaluate the proposed routing protocol and compare it with AODV routing protocol via simulation. For this purpose, we implemented the proposed algorithm on the NS-2 [9] simulator. The performance of the CRP and AODV protocol is evaluated in terms of packet delivery ratio and average end-to-end delay. The packet delivery ratio is defined as the percentage of packets that successfully reach the receiver nodes each second. The average end-to-end delay is defined as the average time between a packet being sent and being received. Figure 4 compares the packet delivery ratio (PDR) for AODV and CRP. As the number of nodes increases the packet delivery ratio decreases. We can see that the packet delivery ratio of CRP is clearly higher than the AODV protocol and our algorithm can scale up to larger network. The comparison of the end-to-end delay is show in Figure 5. We can see that as the total number of nodes increases, the average end-to-end delay increases, because more connections and congestions appear in higher density network. It can also be concluded from this study (Figure 5) that the average end-to-end delay for proposed approach is better than the AODV protocol. When the source node wants to send a message to the destination node and does not already have a valid route to that destination, it initiates a path discovery process to locate the destination.

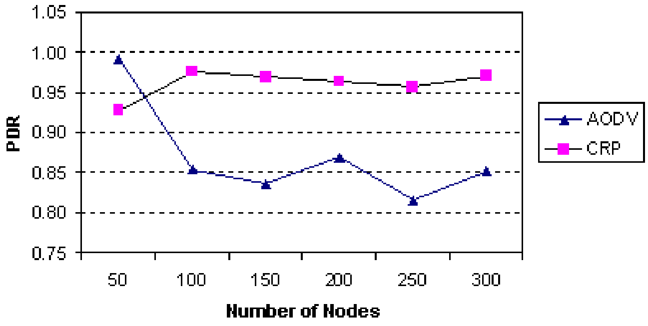

Figure 4: PDR vs. number of nodes

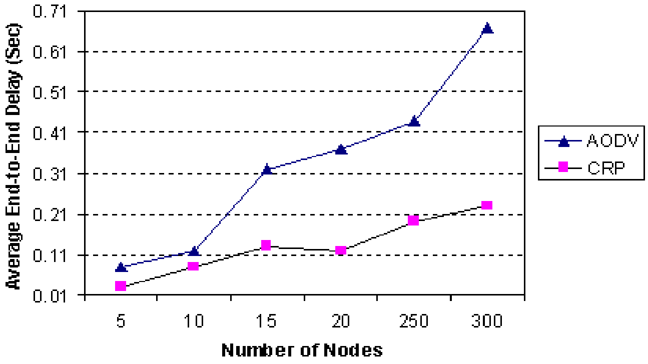

Figure 5: Average end-to-end delay vs. number of nodes

VI.CONCLUSION

A distributed adaptive opportunistic routing scheme for multi hop wireless ad-hoc networks is proposed. The proposed scheme utilizes a reinforcement learning framework to opportunistically route the packets even in the absence of reliable knowledge about channel statistics and network model. This scheme is shown to be optimal with respect to an expected average per packet reward criterion. The proposed routing scheme jointly addresses the issues of learning and routing in an opportunistic context, where the network structure is characterized by the transmission success probabilities. In addition, the proposed routing protocol works on the basis of a virtual cluster, consisting of a collection of only those nodes that are one-hop distance away. The idea is to significantly reduce the control overheads such as route query packets as well as the flooding time for collecting the network topology information at a destination..Due to the increased path length between two end nodes in a multi-hop MANET, scalability is a challenging issue. Further, it introduces the concept of anchors, which are geographical points imagined by sources for routing to specific destinations, and proposes low overhead methods for computing anchors. A large-scale MANET is feasible only when the task of route search is localized so that the corresponding overhead does not increase as network grows. As one of the promising architectural choices for a scalable MANET, the *link cluster architecture* (*LCA*) was discussed, where mobile nodes are logically partitioned into clusters that are independently controlled and dynamically reconfigured with node mobility.

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