An Efficient Routing and Interface Assignment Algorithm for Multi-Channel Multi-Interface (MCMI) *Ad Hoc* Networks

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Abstract. In this paper, a routing and interface assignment algorithm is proposed for MCMI wireless *ad hoc* networks. The algorithm consists of two steps: route selection and interface assignment. The process of route selection is to find the path with the minimum lower bound while the interface assignment is to assign the interfaces on the nodes along the path based on the application of the Viterbi algorithm. The proposed algorithm is computationally efficient due to the decoupling of the route selection and interface assignment processes. Computer simulation and examples are used to demonstrate the effectiveness and performance of the proposed technique. Comparisons are made to other existing routing techniques in the area of dynamical spectrum access.

Keywords: *Ad hoc* networks · MANET · Routing
Multi-Channel Multi-Interface (MCMI) · Viterbi algorithm

1 Introduction

A MANET (Mobile *Ad hoc* Network) is a type of *ad hoc* networks that can be deployed quickly without any prior planning or construction of expensive network infrastructure [1]. In the last two decades, MANET has attracted lots of interest from academics as well as industries. In a traditional MANET, all nodes use a single common channel for communications, which eliminates the need for coordination between adjacent nodes. In addition, the use of single channel links can greatly reduce the cost of a wireless network since each node only needs one wireless interface. However, the throughput capacity of a single channel network is significantly limited due to simultaneous transmission on a same channel [2,3]. A popular approach for improving the network capacity performance is to use orthogonal transmissions among adjacent hops to minimize collision and channel interference. More recently, a trend is to use multiple channels and multiple interfaces (also referred to as radios) on each node as a means for multiple simultaneous orthogonal transmissions (see [4] and references thereafter). The use of multiple interfaces has been accelerated by the recent rapid advancement in communications technologies and hardware systems that are becoming more

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powerful, more compact and less expensive, and more energy efficient. It becomes feasible to fit multiple interfaces on a node to support the use of multiple channels for MANET applications. The widely used technology IEEE 802.11a [5] is already known to support multiple channels by switching from one channel to another. The development of spectrum agile software-defined radio (SDR) [6,7] is another major driving force behind the adoption of MCMI networks. SDRs can be programmed to tune to a wide spectrum range and operate on any frequency bands in the range.

Recently, many routing and medium access control (MAC) protocols have been developed for MCMI networks [4,8–17]. In [19], by assuming that the number of available interfaces on each node is less than the number of the available channels, the authors proposed an interface assignment strategy, in which one interface is fixed for coordination while the others can be switched. Routing heuristics were then discussed. Wu *et al.* [20] proposed a MAC protocol that requires two interfaces on each node: one interface is assigned to a common channel for control messages, and the second one is switched between the other channels for data communications. In [21], a similar 2-interface solution was discussed, in which a channel (or interface) is selected for data communications based on the load of the channel. In [22], a multi-channel MAC protocol is proposed for IEEE 802.11, which requires only one interface on each host and solves the multi-channel hidden terminal problem using temporal synchronization. The development of routing techniques for MCMI networks has some new challenges due to channel diversity and the use of multiple interfaces on each node. Traditional *ad hoc* routing algorithms cannot handle multi-channels efficiently since they are designed for single channel networks. In general, the steps of route selection and channel assignment can be executed either simultaneously or in a decoupled way [15–17]. In [16], a layered graph was proposed to model the discovered spectrum opportunities (SOPs), which is then used to develop efficient and routing and interface assignment algorithms to form near-optimal topologies for dynamical spectrum access (DSA) networks. The construction of the layered graph is to fully utilize the forwarding capability at each node to choose different channels on different hops of a path, and to ensure that adjacent hop interference is minimized. A main shortcoming of the layered graph routing algorithm is the heavy computational complexity involved in the construction of the layered graph and the search for the shortest path due to the increase in the number of compound subnodes in the graph. In [17], a colored multigraph based model was proposed for utilizing spectrum holes for cognitive radio networks. In the colored multigraph model, colored edges are used to represent potential neighbor nodes that share some common channels between them. The goal is to maximize the network capacity and minimize adjacent hop interference among neighboring nodes. The algorithm takes into account the effects of both adjacent hop interference and the number of interfaces available on a current node. This approach is computationally efficient with computational complexity on the order of $O(N^2)$, where N denotes the number of nodes in a network. However, the algorithm only provides locally optimized adjacent hop interference due to the fact that routing selection and channel assignment is executed simultaneously at a local level.

In this paper, we focus on the problem of routing and interface assignment for MCMI networks. More specifically, we try to find the optimum path between a source and a destination nodes given the numbers of available interfaces on each node and the sets of available channels between each pair of nodes in the network. It is assumed that the interfaces on each node can be tuned to different channels but one at a time. We assume that the number of interfaces on each node is less than the number of available channels, and the numbers of interfaces and available channels may differ for each individual node. In this work, we use a common channel approach for resource management including neighbour discovery and exchange of control messages [18,20]. On each node, a dedicated interface is assigned to the common channel. The proposed routing and interface assignment algorithm first finds the shortest path that minimizes the lower bound cost metrics among all feasible routes between the a source and a destination node. Unlike the routing algorithm in [17], channels are not assigned on each hop of the path. In the second step, interface assignment based on the Viterbi algorithm is applied to assign the interfaces on each node along the shortest path to achieve a minimized adjacent hop interference. The Viterbi algorithm is a dynamic programming algorithm for computing the most probable sequence of states in a hidden Markov model given a sequence of observations. In order to apply the Viterbi algorithm, we use a trellis to model the nodes and all available channel along the shortest path. In the trellis, each state represents a channel between a pair of consecutive node on the route. The contribution of the paper is three-fold. First, an effective cost metric is developed, which takes into account the effects of adjacent hop interference and the availability of interfaces on the nodes. Secondly, the idea of decoupling the processes of finding the shortest path and optimal channel assignment is new. The decoupling as well as the use of lower bound metric helps to achieve the globally optimality in routing selection and interface assignment. Thirdly, the Viterbi algorithm is successfully applied in the context of interface assignment for achieving the global optimal adjacent hop interference.

The paper is organized as follows. In Sect. 2, the problem of routing and interface assignment is formulated. Assumptions about MCMI networks are also made in this section. Section 3 is devoted to the development of the proposed routing and interface assignment techniques. In this section, a cost metric is defined, and the algorithm for routing and interface assignment is discussed in detail. Finally, in Sect. 4, computer simulations and examples are used to demonstrate the effectiveness of performance of the proposed routing algorithm. Comparisons are made with other existing routing algorithms for MCMI networks.

2 System Model and Assumptions

Assume that a network consists of N nodes, and that each node has I configurable half-duplex interfaces that can be tuned to one channel at a time.

A half-duplex radio cannot transmit and receive simultaneously, *i.e.*, it can only transmit or receive at a time. It is also assumed that, for each node, there are a maximum M channels available for data communications.

Routing in an MCMI *ad hoc* network can be formulated as the following problem: given a source node s and a destination node t, find the optimum path and assign a channel to an interface on each node along the path so that the resulting path for data transport between the source and destination nodes is optimum. The optimality of the route is measured in terms of a cost metric that accounts for both the number of hops the route traverses and the effects of adjacent hop interference involved.

For the proposed routing technique, it is required that all nodes in the network have the global view of the network. First, each node must detect the neighbor nodes with which it has a direct link, and obtain information about the available number of interfaces and channels on each neighbor node. This process is also referred to as the neighbor discovery. In a single-channel network, since all nodes operate on a same channel, neighbor discovery can be achieved by, for example, all nodes periodically exchanging beacons [27]. In an MCMI network, since all nodes do not stay not on a same channel, they may not always hear each other on all channels. Many neighbor discovery approaches have been developed in the literature for both signal-channel and multiple-channel ad hoc networks in the literature (*cf.* [26] and thereafter). In this work, we use the common channel approach. A common control channel is assumed for all nodes for neighbor discovery and resource management purpose [18,20]. On each node, a dedicated interface is assigned to the control channel for exchange of control messages. The process of neighbor discovery is implemented on the channel similar to the one in OLSR (Optimized Link State Routing) protocol [27]. Each node periodically transmit beacons that contain the list of neighbors, and the numbers of channels and interfaces available to them. The beacons are received by all one-hop neighbors, which enable each node to discover its one-hop neighbors as well as two-hop neighbors. Based on the information from the received beacons, each node regularly floods the topology control information about its up to two-hop neighbors to the entire network. Each node maintains the topology information of the network obtained from the dissemination of the topology control information.

3 Optimum Routing for MCMI Networks

The proposed MCMI routing algorithm consists of two decoupled steps: finding the shortest path and optimally assigning a channel to an interface on each node along the path. The shortest path is defined as the one that has the minimized lower bound cost among among all available paths. In this step, no interface assignment is implemented. The interface assignment algorithm uses the Viterbi algorithm to achieve global rather than local optimality in assigning interfaces on each node along the shortest path.

3.1 Shortest Path with Minimized Lower Bound Cost

The routing is formulated as the problem of finding the shortest path between the source node and the destination node, where the path is the sum of cost metrics defined for all connections along the path between the source node and the destination node. In general, the proposed approach for finding the shortest path uses similar procedures as Dijkstra's algorithm [23]. However, Dijkstra's algorithm is not directly applicable, since it is suitable to networks, where any two nodes are connected with one edge or channel of fixed cost. In an MCMI network, any two nodes may be connected by multiple channels, and the cost of selecting one channel may be different from the selection of another channel due to channel interference. We assign each node a distance value that represents its distance from the source node. Since in an MCMI network, multiple edges (channels) exist between each pair of nodes, we define additional metrics to represent the cost that a node choose one of the available channels for routing data. The cost metric should be able to take into account both the weight of an edge and channel diversity along a path. Figure 1 shows the connection between a current and a neighbor node, where E_p denotes the edges that connect to the current node v_c, and E_c denotes the edges between the current and next neighbor node. We assume that each edge is characterized by a cost of one (hop). It should be noted that the problem of how to define the cost of an edge is not the focus of this study, and the cost assumption is only for the purpose of demonstration. In practice, the edge cost can be extended to include other factors depending on the applications. For example, the cost can be generalized to use the link state of the edge, *i.e.*, a real number that represents the effective capacity and quality of the edge (link).

Definition 1. Let v_c be the current node, and E_{pi} be a channel that connects to v_c. Let E_{ck} be a channel that connects with a neighbor node. The cost of selecting E_{ck}, denoted by c, can be computed according to the following rules:

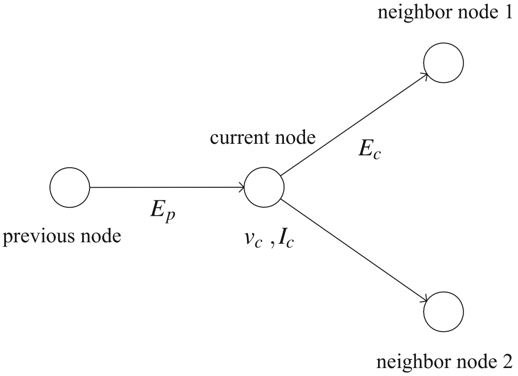

Fig. 1. Connection cost between current and neighbor node.

1 if no interface is available on v_c, $c = \infty$.
2 when v_c has one interface, if E_{pi} and E_{ck} represent a same channel, then $c = 1 + \beta$, where β denotes a penalty term;
3 when v_c has more than one interface, if E_{pi} and E_{ck} are different channels, $c = 1$; otherwise, $c = 1 + \beta$.

The above definition provides the cost metric for connecting to a neighbor node on a given channel. In the following, we define *the lower bound cost metric* for connecting a pair of nodes for the case of multiple channels between the two nodes. Note that in this metric, no specific channel is specified that connects the pair.

Definition 2. Let v_c be the current node. Denote E_p as the channels that connect to v_c, and E_c the available channels between v_c and another neighbor. The cost of selecting the path that connects v_c and v_n is computed according to the following rules.

1 If no interface is available on v_c, $c = \infty$.
2 When v_c has only one interface, if E_p and E_c share at least one common channel, then, $c = 1 + \beta$; The same rule applies when one or multiple consecutive nodes preceding the current node on a path have only one interface.
3 When v_c has more than one interface, if E_p and E_c each has at least one non-common channel, then, $c = 1$; otherwise, $c = 1 + \beta$.

This cost metric defines the minimum cost that v_c connects to v_n given the edges in E_c. In other words, the cost is a lower bound on the cost of selecting any edge from E_c under any given edge in E_p.

The route selection algorithm is used to find the shortest route between the source and the destination node with the minimized lower bound cost metric. All the nodes of the network are classified into two exclusive sets: visited and unvisited. At the beginning, all nodes are marked unvisited. The algorithm iterates over all unvisited nodes until all nodes are marked visited. At each step, a current node will be found and the distances of all its unvisited neighbor nodes will be evaluated and updated. The distance of an unvisited neighbor node is updated as the distance of the current node plus the cost of edges connecting to the neighbor node.

3.2 Interface Assignment

Although the effects of channel availability on each hop is taken into account, channels are not explicitly assigned to interfaces on the nodes. Since there may be more than one channel available between a pair of adjacent nodes on the path, and more than one interface on each node, the interfaces on each node along the path need to be assigned with an available channel in order to minimize the adjacent channel interference [16,17]. In this paper, we use a trellis to describe the interface assignment problem. Let $\mathcal{P}$ denote the shortest path from the route selection algorithm, which is assumed to consists of $l + 1$ nodes. Let $\underline{e}_i$ denote

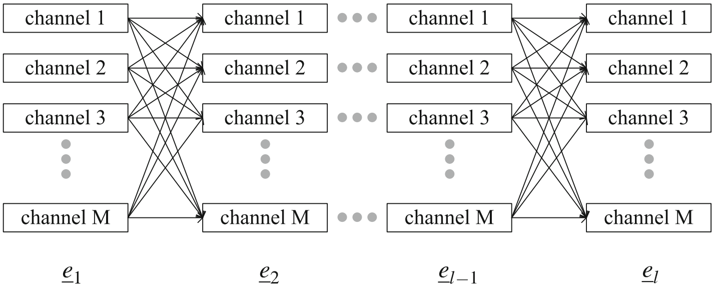

Fig. 2. Cost functions for different scenarios.

channels that are available between the ith and the $(i+1)$th adjacent node on $\mathcal{P}$. The trellis shown in Fig. 2 depicts all connections between the source and the destination when multiple channels exist between pairs of adjacent nodes along the shortest path. The problem is to find the path that has the minimized cost. The Viterbi algorithm [24,25] is perhaps the most popular technique for solving such a problem. The Viterbi algorithm is a dynamic programming algorithm for computing the most probable sequence of states in a hidden Markov model given a sequence of observations. The trellis in Fig. 2 has M states or channels denoted by $\{e_1, e_2, \ldots, e_M\}$. The path $\mathcal{P}$ consists of l hops, which are indexed by i with $1 \leq i \leq l$. The transition cost $\epsilon^{(i)}(j,k)$ is computed according to Definition 1.

The Viterbi algorithm is a recursive approach that runs from $i = 1$ to $i = l$. For each intermediate state in the trellis, the best partial path is computed as the one that has the minimum cost among all paths that end at the state. The algorithm will produce a set of optimum paths that reach the available states on the last hop in the trellis, and the sequence that has the minimum associated partial cost will be selected as the optimum channel assignment. From the state on the last hop on the shortest path, we then can use the back pointers to propagate backwards to recover the optimum path. The application of the Viterbi algorithm has the useful property of using the context of entire information of channels and interfaces on each node along the shortest path for judgement, and is able to provide the global optimum channel assignment solution. The Viterbi type algorithm is also computationally efficient due to the recursive nature of the algorithm.

4 Performance Analysis

In this section, we use two examples to show the performance and effectiveness of the proposed routing and interface assignment algorithm for MCMI *ad hoc* wireless networks. In the first example, a network is simulated, in which the nodes are randomly distributed in a square area of 10 m by 10 m. The simulated network consisted of 30 nodes. The number of interfaces on each node is randomly selected between 1 and 4. The number of available channels between a pair of connected nodes is assumed to be uniformly distributed between 1 and 6.

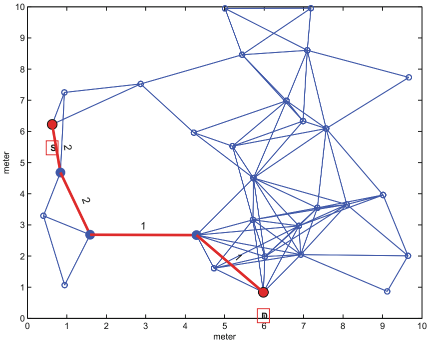

Fig. 3. The optimal route and interface assignment selected by the proposed routing algorithm.

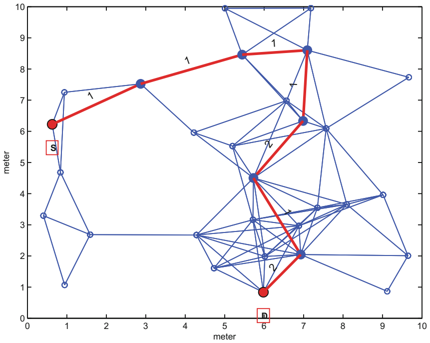

Fig. 4. The optimal route and interface assignment selected by the colored multigraph model based approach.

The penalty due to adjacent hop interference was selected as $\beta = 0.5$, which is equivalent to half of the cost for one hop. Figures 3 and 4 show the routing paths between the pair of source and destination nodes decided by the proposed approach and the colored multigraph model (CMM) based algorithm, respectively. In the figures, it can be seen that, the route selected by the proposed algorithm has 4 hops while the route computed by the CMM based algorithm has to traverse 7 hops for the source and destination nodes. In terms of adjacent hop interference, the route by the proposed algorithm contains two pairs of adjacent hops that have interfering channels while the route by the CMM based algorithm contains 3 pairs. For this example, the proposed routing algorithm outperforms the CMM based algorithm both in the number of hops that the route traverses and the adjacent hop interference. In the simulation studies, it was observed that the proposed routing algorithm had performed better in most case and was never worse than the CMM based algorithm.

Another example is used to demonstrate the flexibility of the proposed routing and interface assignment algorithm in dealing with weighting of adjacent hop interference by selecting different values for the penalty terms. As discussed before, the selection of the penalty value affects both the route selection and and the channel assignment. Increasing penalty value may force the routing algorithm to select a route that consists of more hops and less adjacent hop interference. In some applications, the prevention of adjacent channel interference is critical

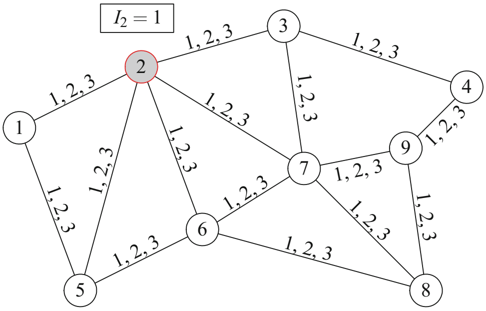

Fig. 5. An example of network for effects of penalty values.

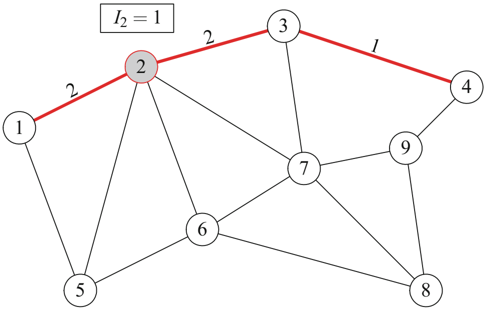

Fig. 6. Optimal route and channel assignment when $\beta = 0.5$ and 1.0.

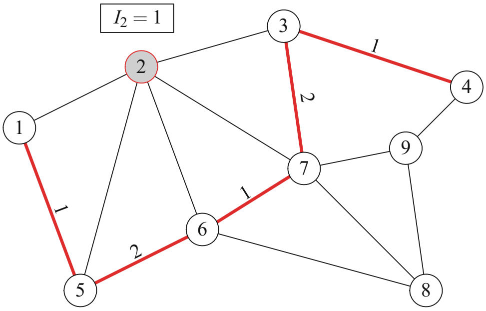

Fig. 7. Optimal route and channel assignment when $\beta = 2.5$.

to the operation of a network because channel interference may form a bottleneck for packet throughput on the selected route. Another advantage of reducing adjacent hop interference is that it can improve spectrum utilization of a network. The simulated network topology is shown in Fig. 5. The network consists of 9 nodes, where node 3 has one interface and the others are assumed to have 2 interfaces on them. Without loss of generality, all connected node pairs have channels 1, 2 and 3 available. First, we set the penalty value to 0.5 and 1, respectively, and apply the proposed routing algorithm. The routing results are shown in Fig. 6. The selected optimal route traverses 3 hops and contains one occurrence of adjacent hop interference at node 2, where the *in* and *out* routes are all on channel 2. The selected route has a minimized cost of 3.5. To demonstrate the effects of penalty value on the route selection algorithm, we increased the penalty value to 2.5. In this case, one occurrence of adjacent hop interference is equivalent to 2.5 hops in cost metric, and is considered a significant penalty for selecting a route with adjacent hop interference for data traffic. The selected route and the interface assignment selected by the proposed algorithm is shown in Fig. 7. The route has successfully avoided the route with adjacent hop interference. However, the tradeoff is an increase in the number of hops that the route traverses. The selected route has a minimized cost of 5.

5 Conclusions

In this paper, an optimized routing and interface assignment algorithm was presented for MCMI wireless *ad hoc* networks. The technique decouples the routing and interface assignment into two steps, *i.e.*, route selection and interface assignment. A cost metric was proposed that accounts for both the number of hops of a route to be traversed and the effects of adjacent hop interference. Unlike traditional path searching algorithms, a lower bound cost metric rather than the cost metric itself is used as the path searching criteria. The Viterbi algorithm is used to assign interfaces on the nodes along the shortest path to achieve the globally minimized adjacent hop interference. Computer simulation were used to demonstrate the effectiveness and performance of the proposed technique. The proposed routing algorithm is computationally efficient, and has the advantage of flexibility in dealing with weighting of adjacent hop interference by selecting different values for the penalty terms. Future studies will include other factors that will affect the routing performance such as switching latency and end-to-end delay.

References

1. Basagni, S., Conti, M., Giordano, S., Stojmenovic, I. (eds.): Mobile Ad Hoc Networking. IEEE Press, Wiley-Interscience, Piscataway (2004)
2. Gupta, P., Kumar, P.R.: The capacity of wireless networks. IEEE Trans. Inf. Theory **46**(2), 388–404 (2000)

3. Grossglauser, M., Tse, D.: Mobility increases the capacity of ad-hoc wireless networks. IEEE/ACM Trans. Networking **10**(4), 477–486 (2002)
4. Kyasanur, P., Vaidya, N.: Routing in Multi-Channel Multi-Interface Ad Hoc Wireless Networks. Technical report, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, December 2004
5. IEEE Standard for Wireless LAN-Medium Access Control and Physical Layer Specification. IEEE Computer Society, IEEE, New York, June 2007
6. Jondral, F.K.: Software-defined radio-basics and evolution to cognitive radio. EURASIP J. Wirel. Commun. Networking **3**, 275–283 (2005)
7. Fette, B.: Cognitive Radio Technology. Elsevier Science & Technology Books (2006)
8. Dang, D.N.M., Nguyen, V., Le, H.T., Hong, C.S., Choe, J.: An efficient multi-channel MAC protocol for wireless ad hoc networks. Ad Hoc Netw. **44**(C), 46–57 (2016)
9. Draves, R., Padhye, J., Zill, B.: Routing in multi-radio, multi-hop wireless mesh networks. In: Proceedings of the 10th Annual International Conference on Mobile Computing and Networking (MobiCom 2004), Philadelphia, PA, USA, pp. 114–128, October 2004
10. Miu, A.K., Balakrishnan, H., Koksal, C.E.: Improving loss resilience with multi-radio diversity in wireless networks. In: Proceedings of the 10th Annual International Conference on Mobile Computing and Networking (MobiCom 2004), Philadelphia, PA, USA, pp. 16–30, October 2004
11. Raniwala, A., Chiueh, T.C.: Architecture and algorithms for an IEEE 802.11-based multichannel wireless mesh network. In: Proceedings of the IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2005), Miami, FL, USA, vol. 3, pp. 2223–2234, March 2005
12. Chereddi, C., Kyasanur, P., Vaidya, N.: Design and implementation of a multi-channel multi- interface network. In: Proceedings of the 2nd International Workshop on Multi-hop Ad Hoc Networks: from Theory to Reality, International Symposium on Mobile Ad Hoc Networking and Computing, Florence, Italy, vol. 5, pp. 23–30, May 2006
13. Maheshwari, R., Gupta, H., Das, S.: Multichannel MAC protocols for wireless networks. In: 2006 Proceedings of the 3rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks (SECON 2006), Reston, VA, USA, vol. 2, pp. 393–401, September 2006
14. Sharma, A., Belding, E.: FreeMac: Framework for multi-channel MAC development on 802.11 hardware. In: Workshop on Programmable Routers for Extensible Services of Tomorrow (PRESTO), Seattle, WA, USA, August 2008
15. Wang, Q., Zheng, H.: Route and spectrum selection in dynamic spectrum networks. In: 2006 Third IEEE Consumer Communications and Networking Conference (CNCC), Las Vegas, Nevada, USA, pp. 625–629, 8–10 January 2006
16. Xin, C., Xie, B., Shen, C.C.: A novel layered graph model for topology formation and routing in dynamic spectrum access networks. In: Proceedings of the 2005 First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN), Baltimore, MA, USA, pp. 308–317, November 2005
17. Zhou, X., Lin, L., Wang, J., Zhang, X.: Cross-layer routing design in cognitive radio networks by colored multigraph model. Wirel. Pers. Commun. **49**, 123–131 (2009)
18. Jain, N., Das, S., Nasipuri, A.: A multichannel CSMA MAC protocol with receiver-based channel selection for multihop wireless networks. In: The 10th IEEE International Conference on Computer Communications and Networks (IC3N), Scottsdale, AZ, USA, pp. 432–439, October 2001

19. Kyasanur, P., Vaidya, N.H.: Routing and interface assignment in multi-channel multi-interface wireless networks. In: IEEE Wireless Communications and Networking Conference (WCNC 2005), LA, USA, New Orleans (2005)
20. Wu, S.L., Lin, C.Y., Tseng, Y.C., Sheu, J.P.: A new multi-channel MAC protocol with on-demand channel assignment for multi-hop mobile ad hoc networks. In: Proceedings of the 2000 International Symposium on Parallel Architectures, Algorithms and Networks (I-SPAN 2000), Dallas, TX, USA, pp. 232–237, December 2000
21. Hung, W.C., Law, K.L.E., Leon-Garcia, A.: A dynamic multi-channel MAC for ad hoc LAN. In: Proceedings of the 21st Biennial Symposium on Communications, Kingston, Ontario, Canada, pp. 31–35, June 2002
22. So, J., Vaidya, N.H.: Multi-channel MAC for ad hoc networks: handling multi-channel hidden terminals using a single transceiver. In: Proceedings of the 5th ACM International Symposium on Mobile Ad Hoc Networking and Computing (Mobihoc 2004), Roppongi Hills, Tokyo, Japan, pp. 222–233, May 2004
23. Dijkstra, E.W.: A note on two problems in connexion with graphs. Numer. Math. **1**, 269–271 (1959)
24. Forney Jr., G.D.: The viterbi algorithm. Proc. IEEE **61**(3), 268–278 (1973)
25. Rabiner, L.R.: A tutorial on hidden Markov models and selected applications in speech recognition. Proc. IEEE **77**(2), 257–286 (1989)
26. Karowski, N., Viana, A.C., Wolisz, A.: Optimized asynchronous multi-channel neighbor discovery. In: Proceedings of the 30th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2011), Shanghai, China, pp. 536–540, April 2011
27. Clausen, T., Jacquet, P. (eds.), Project Hipercom (INRIA): Optimized link state routing protocol (OLSR). The Internet Engineering Task Force (IETF) Network Working Group RFC 3626, Experimental, October 2003