Broadcasting in Multi-Radio Multi-Channel and Multi-Hop Wireless Networks

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Abstract. Multi-radio multi-channel multi-hop wireless networks have recently received a substantial amount of interest. An important question in multi-radio multi-channel networks is how to perform efficient network-wide broadcast. However, currently almost all broadcasting protocols assume a single-radio single-channel network model. Simply using them in multi-channel environment without careful enhancement will result in unnecessary redundancy. In this paper, we propose a general model of the broadcasting problem under multi-channel environment and show the efficient broadcasting problem is NP-hard. Then we reduce the problem into the minimal strong connected dominating set problem of the *interface-extend* graph which extends the original network topology across interfaces. Using interface-extend graph, we describe our Multi-Channel Self-Pruning broadcast protocol and simulation shows that our protocol can significantly reduce the transmission cost.

1 Introduction

A fundamental obstacle to building large scale multi-hop networks is the insufficient network capacity when route lengths and network density increase due to the limited spectrum shared in the neighborhood [1]. The use of multiple radios which tuned to orthogonal channels can significantly improve the network capacity by employing concurrent transmissions under different channels, and that motivates the development of new protocols for multi-radio multi-channel (MR-MC) networks.

An important question in multi-radio multi-channel multi-hop networks which we attempt to address in this paper is how to perform efficient network-wide broadcast in such networks. Broadcasting is frequently used in multi-hop networks not only for data dissemination, but also for route discovery in reactive unicast routing protocols [2]. The presence of several multi-party applications—such as local content distribution and multimedia gaming—also imposes more capacity requirements to the broadcast protocol. However, naive broadcast scheme will generate an excessive amount of redundant traffic and exaggerates interference in the shared medium among neighboring nodes, which is called the broadcast storm problem [3]. A vast amount of broadcasting protocols such as probability-based methods, area-based methods, and neighbor-knowledge-based methods [4] have been proposed to mitigate the broadcast storm problem. However, all of the above protocols assume a single-radio single-channel (SR-SC) model.

There exist large amount of research on channel assignment and protocol design for MR-MC networks, but the study on broadcasting is very limited. The use of multiple radios and multiple channels proposes new challenges to broadcast protocol design. Kyasanur [5] has hinted about some of the potential problems of broadcasting in MR-MC networks. In SR-SC networks with omni-directional antenna, a transmission by a node can be received by all neighboring nodes that lie within its communication range, and this is called 'wireless broadcast advantage' (WBA). However, when multiple channels are being used, a packet broadcast on a channel is received only by those nodes listening to that channel. Simply using the SR-SC broadcast protocols without careful enhancement will result in unnecessary redundancy. For example, in figure 1, node a initials a network-wide broadcast process. Under the SR-SC broadcast protocols which will only choose node b as the forward node, totally 4 transmissions are needed to cover all nodes. However, if we choose node b (use channel 1) and node f (use channel 4) to forward packets, only 3 transmissions are sufficient to complete the broadcast.

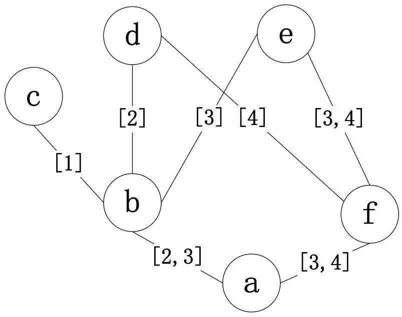

Figure 1. A 6-node network with 4 available channels. The number in [] represents the assigned channel of the link

In this paper, we consider to mitigate the broadcast storm problem in MR-MC networks. The objective is to achieve full coverage, and at the same time reduce the amount of redundant traffic. We show that the efficient broadcast problem in MR-MC environment can be reduced into the minimal strong connected dominating set problem of the interface-extend graph which extends the original network topology across interfaces. Using interface-extend graph, we describe our protocols called Multi-Channel Self-Pruning (MCSP) broadcast protocols, both in static (virtual backbone) and dynamic approach, extending the localized neighbor-knowledge-based broadcast protocols called self-pruning [6][7][8] in SR-SC environment. Our simulation results show that our MCSP protocol can significantly minimize redundant traffic. To the best our knowledge, our work is the first neighbor-knowledge-based broadcast scheme in this area.

The rest of the paper is organized as follows. Section 2 reviews existing broadcast schemes. Section 3 presents the network model and defines the efficient broadcasting problem in MR-MC wireless networks. In Section 4, we propose the *interface-extend* graph and describe the MCSP broadcast protocol and its properties. Simulation results are presented in Section 5, and Section 6 concludes this paper.

2 Related Works

Williams and Camp [4] divided broadcast techniques into four categories: simple flooding, probability-based methods, area-based methods, and neighbor-knowledge-based methods. Blind flooding may be the simplest form of broadcasting. In blind flooding, upon receipt of a new broadcast packet, a node simply sends it to all its neighbors. This, however, causes serious network congestion and collision. In probability-based and area-based methods, each node estimates its potential contribution to the overall broadcasting to make a decision whether or not to forward the packet. Though smaller forward node sets can be generated, they cannot ensure the full coverage. Neighbor-knowledge-based methods are based on the following idea: select a small set of nodes to form a connected dominating set (CDS) as virtual backbone to forward packet. A node set is a dominating set if every node in the network is either in the set or the neighbor of a node in the set. In [10], it is demonstrated that broadcast scheme based on a backbone of size proportional to the minimum connected dominating set guarantees a throughput within a constant factor of the broadcast capacity.

Neighbor-knowledge-based algorithms can be divided into neighbor-designating methods and self-pruning methods. In neighbor-designating methods [11][12][13], each forward node uses a greedy algorithm to selects a few 1-hop neighbors as new forward nodes to cover its 2-hop neighbors. The forward node list is piggybacked in the broadcast packet and each forward node in turn designates its own forward node list. In self-pruning methods, each node determines it own status (forward or non-forward) according the local topology information and broadcast routing history information. Wu and Li [7] proposed a marking process and *Rule k* which can make use of local topology and priority among nodes to determine a small CDS. Peng and Lu's SBA [6] uses a random backoff delay to discover more forwarded nodes, and then uses a neighbor elimination scheme to determine the forward status for each node. A generic self-pruning scheme was proposed by Wu and Dai [8] to unify all the above self pruning protocols. In [14][15][16], some schemes are proposed for broadcasting using directional antennas.

All of the aforementioned protocols assume a SR-SC model. Broadcasting in MR-MC networks is very limited in literature. Kyasanur and Vaidya [5] simply propose to transmit a copy of the broadcast packet on every channel or use a separate broadcast channel at the expense of a dedicated interface. Qadir and Chou [17] design a set of centralized algorithms to achieve minimum broadcasting latency in multi-radio multi-channel and multi-rate mesh networks. However, the centralized approach results in a nontrivial overhead to construct and maintain the broadcast tree.

3 Network Model and Problem Formulation

3.1 Network Model

We consider a multi-radio multi-channel multi-hop network in which all nodes communicate with one another based on the IEEE 802.11 MAC protocol. It's assumed that there are totally C non-overlapping orthogonal frequency channels in the system and each node v is equipped with $I(v)$ omni-directional radio interfaces, $I(v) \le C$. The unit disk graph model is used to model the transmission. A channel assignment scheme A assigns each node v, $I(v)$ different channels denoted by the set: $A(v) = \{a_1(v), ..., a_{I(v)}(v) \mid \forall i, 1 \le a_i(v) \le C; \forall i \ne j, a_i(v) \ne a_j(v)\}$, where $a_i(v)$ represents the channel assigned to ith radio interface of node v. Generally speaking, the channel assignment scheme can be classified into static, dynamic, and hybrid approach [5]. However, in our work, we currently assume that the channel assignment is given independently from our broadcasting because the channel assignment strategy is influenced by many factors, such as the unicast traffic. We further assume the channel assignment is static during the process of broadcasting and can keep the networks connected. Recognizing that channel assignment in MR-MC networks plays an important part in the actual performance, we will jointly consider channel assignment and broadcasting in our future work.

Given a channel assignment scheme A, we can use an undirected graph $G = (V, E)$ to model the MR-MC network topology, where V is the set of vertices and E is the set of edges. A vertex in V corresponds to a wireless node in the network. An edge $e = (u, v, k)$, corresponding to a communication link between nodes u and v under channel k, is in the set E if and only if $k \in A(u) \cap A(v)$ and $d(u, v) \le r$, where $d(u, v)$ is the Euclidean distance between u and v, and r is the communication range of the transmission. Note that G may be a multi-graph, with multiple edges between the same pair of nodes, when the node pair shares two or more channels.

For each node v, $N_k(v)$ denotes the set of neighbors of v that are using channel k, and $N(v) = N_1(v) \cup ... \cup N_c(v)$ is v's neighbor set. Note that a neighbor may appear in several $N_i(v)$.

3.2 Problem Formulation

In SR-SC networks, some nodes (called forward nodes) are selected to form connected dominating set (CDS) to relay the packet. There're two approaches that can be adopted: one is the static approach, i.e. the virtual backbone method, where the CDS is constructed based on the network topology, but irrelative to any broadcasting; another is the dynamic approach, where the CDS is constructed for a particular broadcast request, and dependent on the progress of the broadcast process. In MR-MC environment, we will consider both approaches.

First, we define the forward scheme, F , as a function on V , where $F(v)$ is the set of node v's forward channels, $F(v) \subseteq A(v)$. We use $B = \{v \mid v \in V, F(v) \neq \varnothing\}$ to denote the forward node set. For two nodes $u \in V$ and $v \in B$, we say u is reachable from v under forward scheme F , if $u = v$ or there exists a path P : $(v_1 = v, ..., v_l = u)$, satisfying $v_i \in B$ and $F(v_i) \bigcap A(v_{i+1}) \neq \varnothing$, $i = 1,...,l-1$. For example, in figure 2, under forward scheme $F = \{a[3], b, c[2,3], d[1], e, f\}$ (which means node a uses channel 3, node c use channel 2 and 3, node d uses channel 1 as forward channels, and other nodes don't forward packets), node d can reach node f and b .

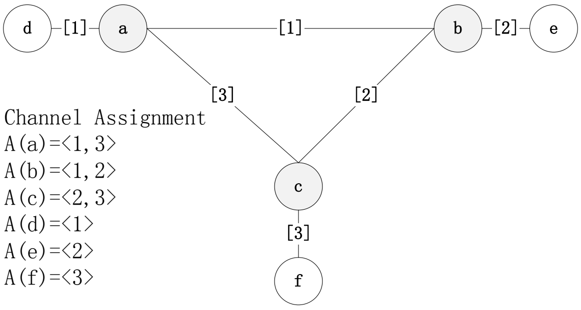

Figure 2. An example for illustration the problem formulation

In the static approach, we say a forward scheme F can form a virtual backbone if $\forall u \in V, \forall v \in B$, u is reachable from v under F . Obviously, for any broadcast process with source node $s \in B$, every other node can receive s' packets. For broadcast process with source node $s \in V - B$, there must exist a node $u \in B$ and $F(u) \bigcap A(s) \neq \varnothing$, so s can send data to node u , then to other nodes. Compared with the broadcasting with source node in B, only one more transmission is needed. For example, in figure 2, both forward schemes $F_1 = \{a[1], b[2], c[3], d, e, f\}$ and $F_2 = \{a[1,3], b[1,2], c[2,3], d, e, f\}$ can form virtual backbone.

In the dynamic approach for a particular broadcast with node s as source node, we say a forward scheme F achieves full delivery if $\forall u \in V$, u is reachable from node s . For example, in figure 2, forward scheme $F_1 = \{a[1], b[2], c[2,3], d, e, f\}$ can achieve full delivery for the broadcast process with source node f .

Our aim is to ensure cover every node, and at the same time reduce the amount of redundant traffic. Next we define the transmission cost of a forward scheme F as $|F| = \sum_{v \in B} |F(v)|$, where $|F(v)|$ is the number of forward channels of node v . So our efficient broadcasting problem in MR-MC networks can be defined as follows: given networks G under channel assignment scheme A, find the forward scheme F with minimum transmission cost $|F|$ that can form a virtual backbone in the static approach or achieve full delivery in the dynamic approach. Obviously, forward scheme $F = \{a[1], b[2], c[3], d, e, f\}$ can form a virtual backbone with minimum transmission cost in figure 2.

Efficient broadcasting in SR-SC networks is a special case of the above problem with $C = 1$. It is equal to find the minimal connected dominating set (MCDS) which is proved to be NP-complete [18]. So we can also conclude that it's NP-hard to find an efficient broadcasting scheme for a MR-MC network under a given channel assignment scheme.

4 Proposed Scheme

We first review the self-pruning protocol [8] under omni-directional SR-SC model as a trivial example solution to the above problem. In [8], each node computes the coverage of its neighborhood. A neighbor node v is covered from the view of node u if $\forall w \in N(u), w \neq v$, there exist a replace path that connects w and v via several intermediate nodes (if any) with higher priority values than the priority value of u. If all neighbor nodes are covered from the view of v, v has a non-forward node status, otherwise, it will forward the packet.

Under MR-MC model, in figure 2, from the view of node a, all neighbors are not covered, he will select channel 1 and 3 as forward channels to cover all neighbors. Simply using the scheme of [8] will result in the forward scheme $F = \{a[1,3], b[1,2], c[2,3], d, e, f\}$. Though forming a virtual backbone, F is apparently not the most efficient scheme.

In SR-SC networks with omni-directional antennas, a transmission by a node can be received by all neighboring nodes within its communication range. The 'wireless broadcast advantage' (WBA) makes broadcasting in SR-SC wireless networks fundamentally different from broadcasting in wired networks where the cost to reach two neighbors is generally the sum of the costs to reach them individually. This arise the shift in paradigm from the 'link-centric' nature of wired networks to the 'node centric' nature of wireless communications. However, when multiple radios and multiple channels are used, a packet broadcast on a channel is received only by those nodes listening to that channel. Motivated by the above example, we argue that we should shift the paradigm from the 'node centric' to 'channel/interface centric' in MR-MC environment. In this section, we will reduce the efficient broadcast problem in MR-MC environment into the minimal strong connected dominating set problem of the *interface-extend* graph which extends the original network topology across interfaces. Then we propose our Multi-Channel Self-Pruning (MCSP) broadcast protocol, both in static and dynamic approach and describe its property.

4.1 Extended Graph G Across Interface

In this subsection, we extend the original graph G into *interface-extend* graph G'. The basic idea here is to treat every interface of every node in MR-MC networks as a vertex of a directed graph. Using interface-extend graph, we will show the efficient broadcast problem in MR-MC environment can be reduced into the minimal strong connected dominating set problem of G'.

Definition 1: Interface-Extend Graph

For an undirected connected graph $G = (V, E)$, we construct a directed graph $G' = (V', E')$, where $V' = \{v_i \mid v \in V, i = 1, ..., I(v)\}$ is the set of vertices and $E' = \{< v_i, u_j > \mid v = u \,\&\, i \neq j \text{ or } v \neq u \,\&\, (v, u, a_i(v)) \in E\}$ is the set of directed edges. We call G' the interface-extend graph of G.

Figure 3 shows the interface-extend graph of figure 2.

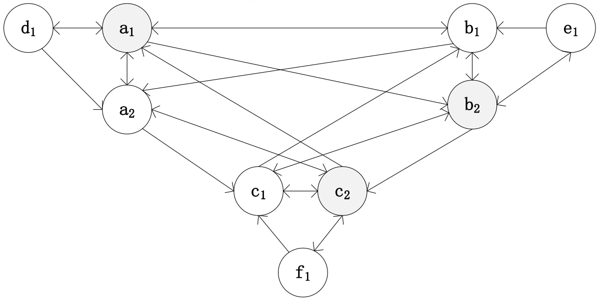

Figure 3. Interface-extend graph of figure 2

Definition 2: Strong connected dominating set

In a strong connected directed graph $G' = (V', E')$, a set $S' \subseteq V'$ is a strong connected dominating set of G' if every vertex in $V' - S'$ is dominated by at least one vertex in S' (i.e. $\forall v' \in V' - S'$, $\exists u' \in S'$ satisfying $< u', v' > \in E'$) and the deduced graph $G'[S']$ is strong connected (i.e. $\forall u' \in S', \forall v' \in S'$, there exists a directed path in $G'[S']$ from u' to v'). For example, in figure 3, vertex a_1, b_2 and c_2 form a strong connected dominating set.

Next, we use the following theorem to reduce the broadcast problem in MR-MC networks G into the minimal strong connected dominating set problem.

Theorem 1 To find the virtual backbone with minimum transmission cost for a MR-MC network G is equivalent to find the minimal strong connected dominating set of the interface-extend graph G'.

Proof. Let $F^* = \{F \mid \textit{forward scheme F that can form a virtual backbone in G}\}$, $D^* = \{D \mid \textit{D is a strong connected dominating set of } G'\}$, and $g: F^* \to 2^{V'}$, $g(F) = \{v'_{i,m} \mid i \in B, a_m(i) \in F(i)\}$. From definition 2, we can prove $g(F) \in D^*$ and $|F| = |g(F)|$.

For $\forall D \in D^*$, we can construct a forward scheme F, $F(v_i) = \{m \mid v'_{i,m} \in D\}$, $\forall v_i \in V$. It's easy to verify that F forms a virtual backbone of G and $g(F) = D, |F| = |D|$.

We can also prove $\forall F_1, F_2, F_1 \neq F_2, g(F_1) \neq g(F_2)$. So g is a bijective mapping from F^* to D^* and $|F| = |g(F)|$. And the virtual backbone with minimum transmission cost in MR-MC networks G can be reduced into the minimal strong connected dominating set problem in directed graph G'. □

4.2 Multi-Channel Self-Pruning (MCSP) broadcast protocol

Theorem 1 mplies that we can get the best forward scheme through seeking for the minimal strong connected dominating set of correspond interface-extend graph. The localized approximation algorithms for minimal strong connected dominating set have been studied in [9]. In this subsection, using the localized interface-extend graph, we propose our MCSP broadcast protocol, extending the self-pruning protocol in [8][9]. We redefine new priority among all interfaces using a combination of node ID and the interface/channel properties (such as channel degree $|N_k(v)|$, interface ID and so on). For other self-pruning protocols, they also can be adapted with some modification.

In MCSP, neighborhood information can be collected via exchanging “Hello” messages among neighbors. Periodically, each node broadcasts "Hello" packets on each channel. In the kth round of information exchange, the hello packet contains $(k-1)$-hop neighbor’s channel assignment and priority information. After m round of information exchange, where generally $m \le 3$, each node can build its local $(m-1)$-hop interface-extend graph.

Figure 4 shows the MCSP algorithm for virtual backbone construction in the static approach.

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Algorithms MCSP (the static virtual backbone approach)
For each node $v$
1. Calculate the uncovered interface set Uncovered_Set$_i$, for every interface $v_i$ ,
   $i = 1,...,I(v)$ in the interface-extend graph $G'$
2. Uncovered_Set = $\sum_{1\le i\le I(v)}$ Uncovered_Set$_i$
3. Calculate the uncovered node set from Uncovered_Set
4. If Uncovered_Set $=\varnothing$ , node $v$ has a non-forward status, otherwise use greedy algorithm to
   compute the forward channels $F(v)$ that cover all the uncovered neighbors.
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Figure 4. MCSP algorithm in virtual backbone approach

Similar to the coverage condition of [8], we say an interface w is covered from the view of u if w is an out-neighbor of u , and for any u ’s in-neighbor v , there exist a replace path that connects from v to w via several intermediate nodes (if any) with higher priority values than that of u . Note that here u , v and w are all interfaces of the interface-extend graph.

Every interface can make decision independently. However, interfaces on the same node can interact with each other without extra communication cost. So in the above algorithm, every interface first calculates its own uncovered neighbors, then we combine them and use greedy algorithms to reselect forward channels in order to save extra transmission. In the example of figure 2, if we use channel degree $N_k(v)$ as interface’s priority, MCSP will mark the interface a_1 , b_2 and c_2 to forward, which form a minimal strong connected dominating set of figure 3.

We also present the MCSP algorithm in the dynamic approach in Figure 5.

In the dynamic approach, every node can use broadcast routing history to further eliminate the uncovered neighbors. Broadcast routing history can be piggyback in the packet. In the example of figure 1, when node a initials a broadcast process, it will use channel 3 to cover all its neighbors, and then node b will use channel 1, node f will use channel 4 to forward packets. Please note that the broadcast scheme of the dynamic approach sometimes can't form a virtual backbone. In figure 1, when node c initials a broadcast, the above forward scheme can't achieve full delivery.

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Algorithms MCSP (the dynamic approach)
1.  For source node $s$, use greedy algorithm to compute the forward channels $F(s)$ that cover all neighbors
2.  For other node $v$, when $v$ fist receives a new packet
    2.1. For each interface $v_i$ of node $v$, compute the uncovered interface set
        2.1.1. Forward_Set_i = all known forwarded interface
        2.1.2. Covered_Set_i = Forward_Set_i + { $N_{out}(v') \mid v' \in$ Forward_Set }
        2.1.3. While there exists an interface $w' \in N_{out}(u')$, $u' \in$ Covered_Set and Priority ( $u'$ ) > Priority ( $v_i$ )
               Covered_Set_i = Coverws_Set +{ $w'$ },
        2.1.4. Uncovered_Set_i= $N_{out}(v_i)$ - Cover_Set_i
    2.2. Compute the forward channels
        2.2.1. Uncovered_Set = $\sum_{1 \le i \le I(v)}$ Uncovered_Set_i
        2.2.2. If Uncovered_Set $= \varnothing$, node $v$ has a non-forward status, otherwise use greedy algorithm to compute the forward channels $F(v)$ that can cover all the un-covered neighbors.
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Figure 5. MCSP algorithm in the dynamic approach

Following theorem guarantees that the MCSP protocol in the dynamic approach can assure every node eventually receives the broadcast packet of the source node s.

Theorem 2. The forward scheme determined by MCSP in the dynamic approach achieves full delivery.

Proof. We use contradiction to conclude the theorem. Suppose there exists a non-empty node set $M \subseteq V$ that every node in M is not reachable from the source node s. Let $M' = \{v_i \mid v \in M, i = 1, \ldots, I(v)\}$. So there must exist a non-empty interface set $U' \subseteq N_{in}(M') - M'$ in which every interface in U' is reachable from one interface of the source node s. Let $u_k = \max_{v_i \in U'}\{priority(v_i)\}$. Let $v' \in N_{out}(u_k) \bigcap M'$. u_k doesn't forward packet, so v' is covered from local view of u_k. However, according to 2.1.1-2.1.3, v' cannot be covered, because:

1. If v' is a known forwarded interface (2.1.1) or v' is a neighbor of a known forwarded interface (2.1.2), v' is reachable from one interface of the source node s, which contradicts the assumption that $v' \in M'$.
2. If v' is an out-neighbor of a covered interface w' and Priority (w') > Priority (u_k) (2.1.3), according to the loop of 2.1.3, there exists a path *P*: $(x', y_1', y_2', \ldots, y_l', v')$ from a known forwarded interface x' to interface v',

where Priority (y_i') > Priority (u_k), i=1,2,...,l. Because $v' \in M'$, there is at least one interface y_j' in P that is reachable from one interface of s but $y_{j+1}' \in M', 1 \le j \le l$, so, $y_j' \in U'$, but Priority (y_j') > Priority(u_k), which contradicts the assumption that u_k is the interface in U' that has the highest priority. □

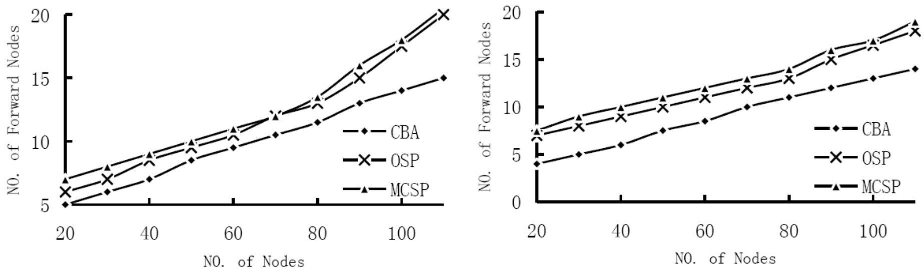
5 Simulation

The proposed MCSP protocols have been implemented in ns-2. For comparison purpose, we implement a centralized broadcast algorithm (CBA) which is similar to what Das et al. [19] proposed. The centralized broadcast algorithm finds the forward scheme by growing a directed tree T in the interface-extend graph starting from an interface with the maximum channel degree, and adding new interface to T according to its effective channel degree (number of neighbors that are not covered). Then we can translate T to the resulting forward scheme. The centralized style makes the algorithm unpractical since it requires global information to compute the forward scheme. However, it can produce a near-optimal result. Here we use it as a substitution of the "perfect" algorithm that produces the optimal forward scheme. The original self-pruning protocols (OSP) [8] are also implemented for comparison. We evaluate the above 3 algorithms both in static and dynamic approach in terms of efficiency and reliability.

The simulated MR-MC network is deployed in a 1000m×1000m area with 20-110 nodes. Each node is equipped with four radios and twelve 2Mb/s channels are available in the system. The communication range for all nodes is 250m and the interference range is 500m. All nodes are randomly deployed and interfaces are randomly assigned with a constraint of full network connectivity. The "Hello" message interval is *1*s and every node gathers *2*-hop local topology and channel assignment information. 1-hop broadcasting routing history information is piggybacked in the broadcast packet. We use channel degree $|N_k(v)|$ followed by interface ID and node ID to break tie as interface's priority value.

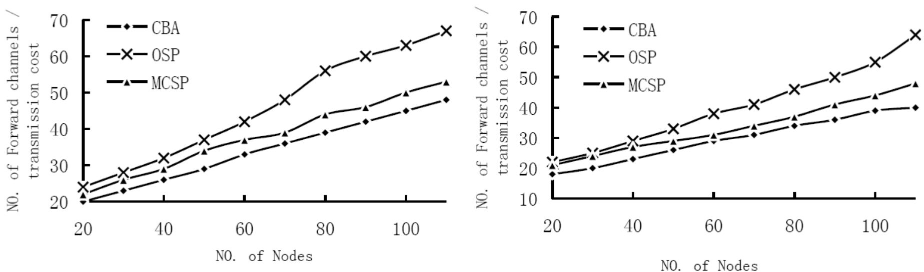
Figure 6 and 7 present the comparison of CBA, OSP and MCSP in generated number of forward nodes and forward channels. Generally speaking, the static approach has a larger set of forward nodes and forward channels than dynamic approach. The centralized broadcast algorithm (CBA) has the smallest set of forward node set and forward channels. The OSP protocol have a little smaller forward nodes set than MCSP protocol, but has much more forward channels thus more transmission cost than MCSP protocol, especially when node number is large. When node number is larger than 60, MCSP can save 25-30% of OSP's transmission cost.

MCSP and other neighbor-knowledge-based broadcast protocol can cover all nodes. But because of the deficiency of the contention-based 802.11 MAC mechanism, collisions are likely to occur and cause some damage. Fig. 8 compares reliability in terms of delivery ratio. Flooding achieves almost 100 percent delivery in networks with more than 50 nodes. The delivery ratios of MCSP and OSP are less than that of flooding, but when the node number is larger than 100, they achieve almost the same level.



(a) (b)

Figure 6.Forward node number. (a) in static approach (b) in dynamic approach



(a) (b)

Figure 7. Transmission cost. (a) in dynamic approach, (b) in static approach

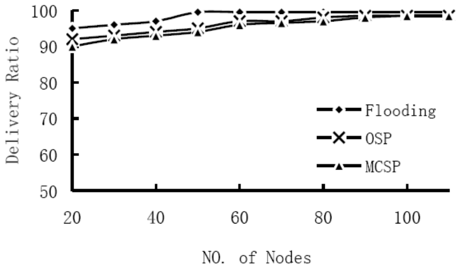


Figure 8. Delivery ratio versus network size

6 Conclusion

This paper aims to provide a general model for broadcasting in multi-radio multi-channel multi-hop networks that uses self-pruning techniques to reduce the transmission cost. We reduce the efficient broadcast problem into the minimal strong connected dominating set of the interface-extend graph. We propose our MCSP protocol, both in virtual backbone approach and dynamic approach. The simulation result shows that our protocol can significantly reduce the transmission cost. In our future work, we will jointly consider the channel assignment and broadcasting problem that will take into account the impact of interference.

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