Transmitter macrodiversity in multihopping

SFN based algorithm for improved node reachability and robust routing

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***Abstract*—** A novel idea presented in this paper is to combine multihop routing with single-frequency networks (SFNs) for a broadcasting scenario. An SFN is a set of multiple nodes that transmit the same data simultaneously, resulting in transmitter macrodiversity. Two of the most important performance factors of multihop networks, node reachability and routing robustness, are analyzed. Simulation results show that our proposed SFN-D routing algorithm improves the node reachability by 37 percentage points as compared to non-SFN multihop routing. It shows a diversity gain of 3.7 dB, meaning that 3.7 dB lower transmission powers are required for the same reachability. Even better results are possible for larger networks. If an important node becomes inactive, this algorithm can find new routes that a non-SFN scheme would not be able to find. Thus, two of the major problems in multihopping are addressed; achieving robust routing as well as improving node reachability or reducing transmission power**.**

Keywords— OFDM, single-frequency networks (SFN), DSFN, MANET; multihop routing, transmitter macrodiversity, broadcasting.

I. Introduction

An important trend in emerging wireless technologies is low-cost infrastructure and dynamic radio resource management schemes that reduce expensive man-power for manual network planning. An example of this trend is wireless multi-hop networks, which are wireless nodes that are capable of dynamically forming a temporary network without any established infrastructure [1]. Whenever needed, intermediate nodes forward data from a source node to the destination nodes. The network is dynamically self-structured and self-constructed where the nodes in the network can establish and maintain mesh connectivity automatically among them [2]. Possible application examples are mobile ad-hoc computer networking (MANET), sensor-actuator networks, visual sensor networks, ultra-wideband (UWB) wireless-USB routers, and wireless digital radio and TV distribution.

A broadcasting service is desirable since it would feature efficient transmission of data from a source (typically an access point) to a vast amount of nodes – as opposed to sending the same data to one node at a time using unicasting. Broadcasting application examples are actuator control data, software updates and real-time multimedia distribution.

Multihop network nodes are often battery driven devices, requiring low energy consumption and low transmission power, resulting in short *transmission range* or coverage area of each node [3]. *Node reachability* or *coverage probability* is the probability that a destination node is within the transmission range of either the source node or a forwarding node, i.e. that a multihop routing path can be formed from the source to the destination node. A non-reachable node is said to be in a state of *outage*. A reachability of *p* corresponds to an outage probability of 1-*p*.

Transmitter macrodiversity implies that several nodes transmit the same signal simultaneously to a destination node or a forwarding node. In cellular communication, this may be used for so called soft-handover. Using radio/TV broadcasting terminology, the group of transmitters sending the same signal are said to form a *single-frequency network* (SFN) [4]. This can improve the received signal strength and coverage area as compared to non-SFN schemes [5]. OFDM modulation [6] can efficiently eliminate inter-symbol interference (ISI) and combat fading caused by this artificial multi-path propagation. Changing the SFN formation adaptively is called Dynamic Single Frequency Networks (DSFN). DSFN may improve the system spectral efficiency in bit/s/Hz/site by a factor of more than 4 in a simple cellular network [7].

Robust routing means that a new path can be found when one or more nodes die, e.g. due to lack of power supply. A *key node* is very important since a whole network section depends on that it can forward data. The key node typically consumes much more energy than other nodes since it is forwarding data so often, meaning that it will die earlier than other nodes. As a result network sectioning or network collapse may occur, which is one of the major problems of multihopping algorithm.

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II. Algorithms

Two ideas; multihop routing and transmitter macrodiversity for a broadcasting service will be combined in our proposed SFN-D algorithm in order to reduce outage probability and increase the routing robustness.

A. *A Simple Example*

Suppose there are 6 nodes in a network. See fig. 1. The source N1 (typically the access point AP) will try to broadcast to as many of the other nodes as possible. Node N2 is within the transmission range (or node coverage area) of N1. Multihop routing results in that also node N2, N3 and N4 can be reached, since N2 and N3 are forwarding data. Node N5 and N6 can not be reached, but are in a state of outage even after multihopping. The coverage probability including node N1 is 4/6=66.7%, corresponding to an outage probability of 33.3%.

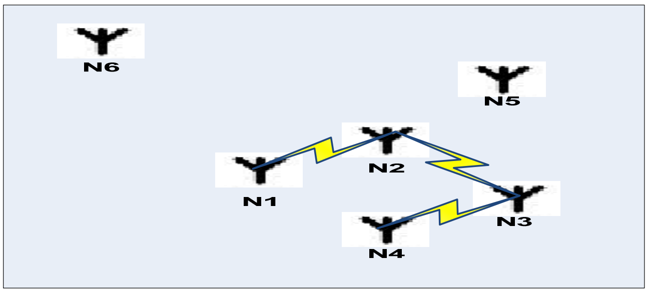

Fig. 1: Four nodes are connected with non-SFN multihopping

Fig. 2 shows that an SFN formation algorithm is applied. If node TX1, TX2, TX3 and TX4 form an SFN and send the same data simultaneously, the *network coverage area* (the white area) is extended, and RX5 can be reached within the coverage area. But still RX6 are out of coverage and is in a state of outage. The coverage probability including node N1 is 5/6 = 83.3%. The improvement is 16.7 percentage points.

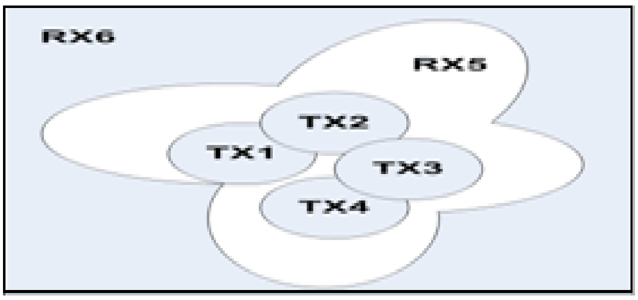

Fig. 2: SFN formation with 4 transmitters makes it possible to connect a fifth node

A simple SFN formation algorithm that assigns a minimum number of transmitters to an SFN follows [7]:

1. Start with an empty set of transmitters assigned to the SFN.
2. Include the transmitter that is nearest to the receiver node in the SFN transmitter set
3. If the signal-to-noise ratio is sufficient, stop. Success.
4. If all the already connected nodes are added, stop. The receiver node is in a state of outage.
5. Add the nearest transmitter that is not already included.
6. Go to step 3.

B. *Non-SFN multihopping algorithm*

As a reference case, a non-SFN multihopping algorithm is evaluated. This algorithm is based on two steps where connected nodes of the access point are found out at the first step and multihopping is employed to increase the coverage area at last step. A JSP (Jackson structured programming) chart of the non-SFN multihopping algorithm follows

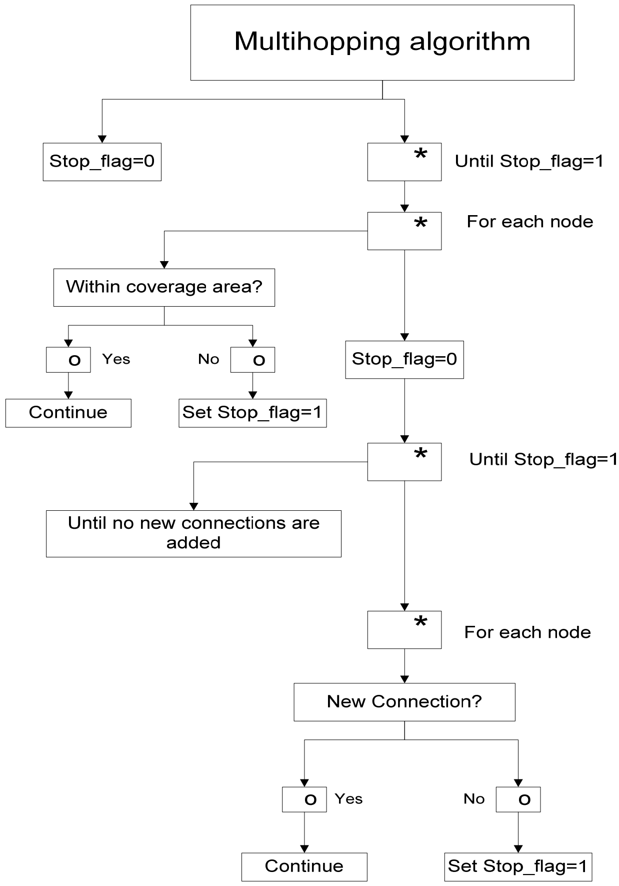

Fig. 4: JSP chart of the non-SFN multihopping algorithm. Asterisk (*) indicate iteration. Circle (o) indicates selection.

C. *SFN-D algorithm*

The primary objective of the SFN-D algorithm is to form minimum size SFNs whenever increased network coverage can be achieved. It should however use non-SFN multihopping whenever possible, since sending from several transmitters would cause higher energy consumption in the network. See fig. 5. N1 and N2 are connected nodes and the source node (AP) is able to reach N1 and N2 since they are within the coverage area of AP. N1 is able to reach N3 and N2 is able to reach N4 through multihopping. N3 is able to reach N5 and N5 is able to reach N6 through multihopping. N5 and N6 will form SFN to reach N7. And at last N7 can reach to N8 through multihopping.

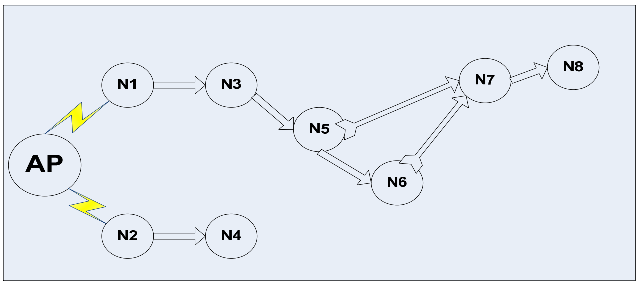

Fig. 5: Simple network of SFN-D algorithm

This algorithm is divided into several steps where connected nodes of the access point are found out at the first step. Then multihopping is employed to increase the coverage area and then SFN is deployed to reduce the outage probability. This algorithm has given more priority to multihopping in comparison with SFN formation. Because multihopping will be employed at first and SFN formation will not be employed until and unless it is required to reach distant nodes. SFN will be employed when multihopping fails to reach any node and then again multihopping will be employed to continue. Overlapping of steps will continue until Max SFN size fail to detect any node. Pseudo code of SFN-D algorithm is as follows

```
1. Try direct connection of nodes with access point (one hop).
2. Try multihopping, over and over again.
Until no new connections are added.
3. Try SFN size 2.
If new connection: Go to step2.
4. Try SFN size 3.
If new connection: Go to step2.
Same as previous.
Etc.
Stop when Max SFN size is reached.
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III. Simulation Model

Fading, routing initiation phase and protocol timing are not considered in our proposed SFN-D algorithm. The following exponential wave propagation model is assumed, where the signal strength $P_{i,j}$ receiver in node j and transmitted from node *i* is:

$$P_{i,j} = \frac{G_{i,j} P_i}{d_{i,j}^{\ \alpha}} \quad \text{(Eq. 1)}$$

Here P_i is the transmission power of node *I*; $d_{i,j}$ is the distance from node *i* to *j*; α is an exponent; and $G_{i,j}$ =G is a path gain factor that depends on carrier frequency, antenna heights, fading, etc, but is here assumed to be constant.

The received signal strength is different for different OFDM sub-carriers, but since all inter-symbol interference (self-interference) is assumed to be eliminated, the average received signal strength in node *j* is assumed to be the sum of the signal strengths from all transmitters belonging to the SFN. This means that the signal-to-noise ratio (SNR) at receiver *j* can be modeled according to the following:

$$SNR_j = \frac{\sum_{i \in SFN} P_{i,j}}{N} \quad \text{(Eq. 2)}$$

Where *N* is the noise and interference power. The values of these parameters can be calculated from the following table.

TABLE 1: Simulation Parameters

Factors	Values
Topology size	100·100meter^2
Node density	0.01/meter^2
Propagation exponent	4
Range of each node	10 meters
Range of access point	20 meters
Transmission power	-10.3 dBm
Receiver sensitivity	-80.5 dBm
Required SNR	4 dB
Size of a packet	1024 bit
Transmission or reception energy/packet	25nJ

IV. Simulation Results

Both the algorithms were simulated based on some predetermined factors and those were very important while comparing them based on reachability and routing robustness. The better algorithm is the one that reaches highest reachability.

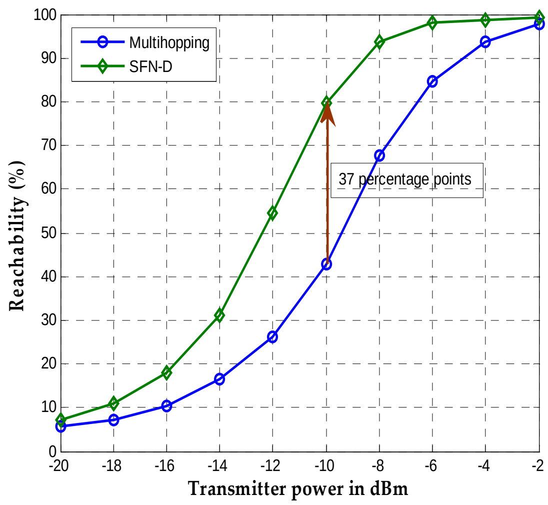

Fig. 6: Comparison of two algorithms

Fig. 6 shows SFN-D have reached 98% reachability in -6 dBm whereas multihopping needs -2.47 dBm to reach equal amount of reachability. At a certain Tx power (-10dBm) algorithm SFN-D have 79% and non-SFN multihopping have 42% of reachability and SFN-D bears more reachability by 37 percentage points. Fig. 7 shows SFN-D achieved 46 percentage points more reachability than non-SFN multihopping for the network size 210·210 m^2 and can maintain it also for larger network sizes.

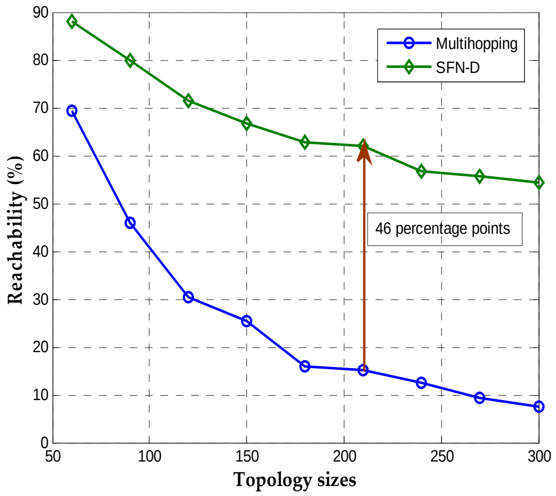

Fig. 7: Comparison of two algorithms

The efficiency of SFN-D algorithm will be tried to find out based on routing robustness. A case will be displayed and analyzed here in order to prove the robustness of that algorithm. The access point is sited in the middle where red circle bears its range and all other nodes are random by position. Blue lines represent the direct connection between access point and the nodes, red lines represent the multihopping and green line represents SFN formation. See fig. 8 and 9.

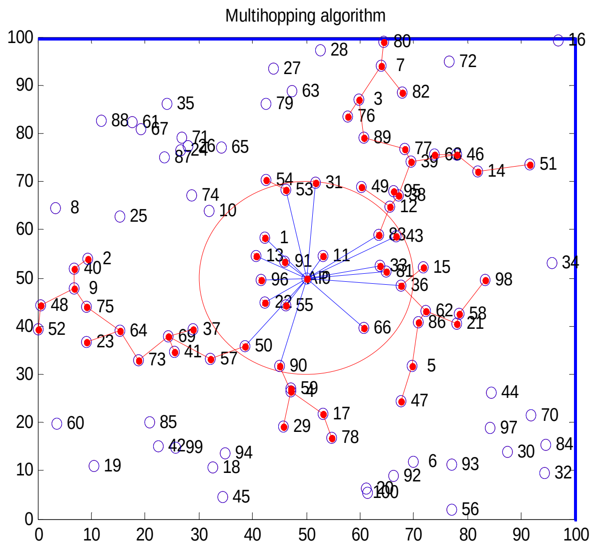

Fig. 8: Example of multihopping algorithm

The non-SFN multihopping algorithm has the reachability of 60% whereas SFN-D bears the reachability of 78%. So, SFN-D has raised the reachability by 18 percentage points. In fig. 10, node 64 and node 89 can be said as the important nodes since a large number of nodes use them as a route. When node 64 and node 89 die, access point looses its connection with those nodes.

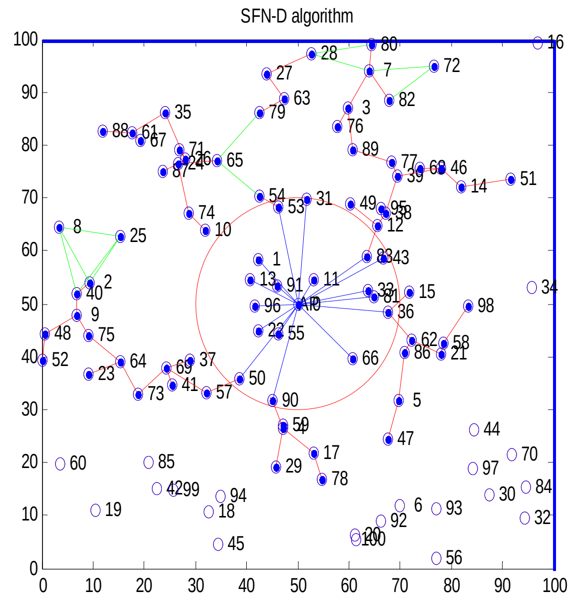

Fig. 9: Example of SFN-D algorithm

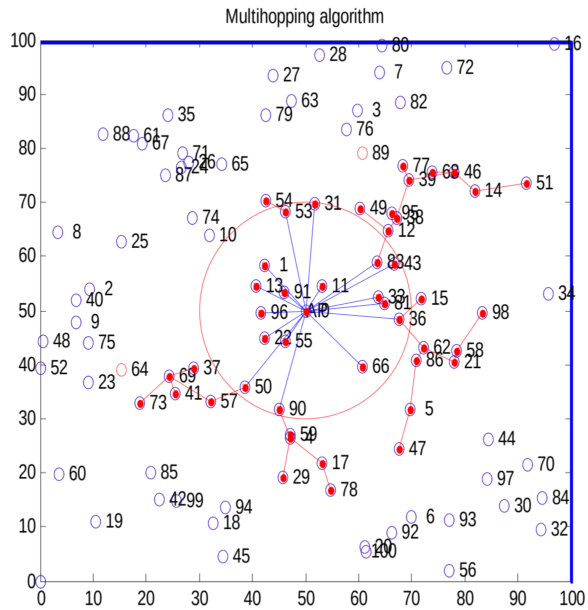

Fig. 10: Some nodes are dead in multihopping algorithm

SFNs are formed to transfer data when node 64 and node 89 die. As a result the network does not loose too much of routing robustness and the network remains stable with rest of the nodes. See fig. 11.

In fig. 12, another two important nodes are going to be killed in SFN-D algorithm which is node 62 and node 12 where a huge number of nodes are dependent on them use them as a route for data transfer.

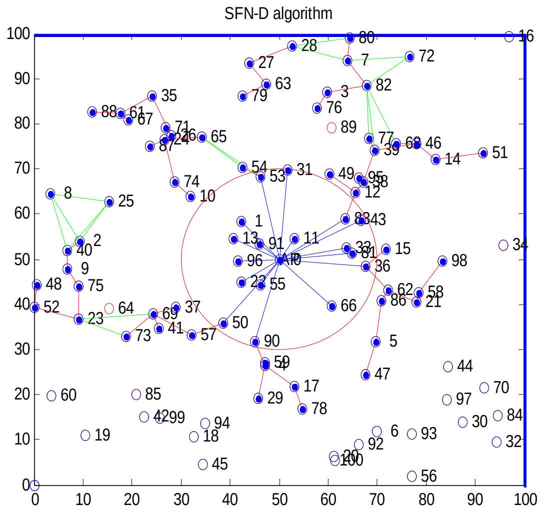

Fig. 11: Some nodes are dead in the SFN-D algorithm

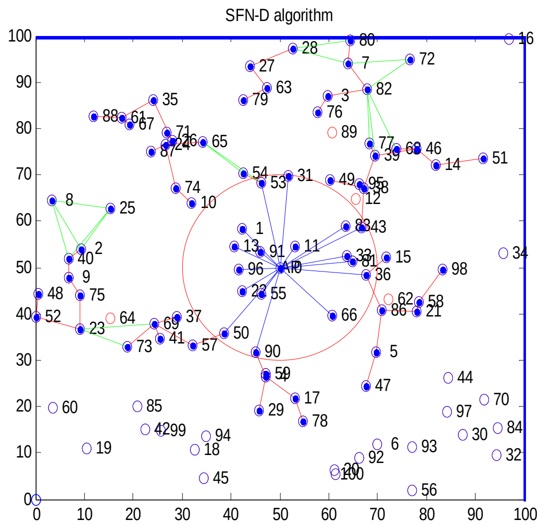

Fig. 12: Some more nodes are dead in the SFN-D algorithm

Two simple multihopping are formed for these two nodes and access point can easily access those rests of the nodes even without SFN formation.

V. CONCLUSION

The results of this study shows that the node reachability was improved by up to 37 percentage points as compared to non-SFN multihop routing. SFN-D only requires transmission power of -8.7 dBm where non-SFN multihopping requires -5 dBm to maintain a node reachability of 90%. This means that the algorithm provides a diversity gain of 3.7 dB. The results indicate that the algorithm is capable of producing even better diversity and reachability gain for larger networks than the simulated 100 nodes.

Most importantly this algorithm addressed one of the key problems of multihopping since it is capable of keeping the network robust even if one or more important nodes die. If a key node becomes inactive, this algorithm can find new routes that a non-SFN scheme would not be able to find by forming an SFN. Consequently, network partitioning is avoided.

A return path may not always be available from a node that only can be reached from an SFN. During the routing initiation phase, when SFNs are formed, a two-way communication path is required for exchanging signal strength measurements. A node that can not be reached during the initiation phase, before SFNs are formed, can not be assigned to an SFN. A conceivable solution to these problems is to increase the transmission power and/or use more robust but less efficient transmission such as a spreading code during the routing initiation and for the return path.

Future work include studying energy consumption, protocol design and timing, routing initiation and distributed algorithm implementations. The concept can be applied to unicasting and multicasting, and combining or comparing SFNs with other dynamic radio resource management techniques, for example ARQ, link adaptation and power control.

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REFERENCES

[1] Josh Broch, David A. Maltz , David B. Johnson, and Yih-Chun Hu, *A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols*,Computer Science Department, Carnegie Mellon University, Pittsbur~, PA 15213,Year of Publication: 1998

[2] Blanca Alicia Correa , Laura Ospina, and Roberto Carlos Hincapie, Survey of clustering techniques for mobile ad hoc networks, Universidad Pontificia Bolivariana, Group Research, Development and Application in Telecommunications and Informatics (GIDATI). Faculty of Engineering. 1a Circular No. 70-01. Medellin,Colombia. Received 25 January 2007, Accepted on 12 April 2007.

[3] Qiangfeng Jiang, and D. Manivannan, *Routing Protocols for Sensor Networks*, Department of Computer Science, University of Kentucky, Lexington, KY, USA,Date: 5-8 Jan. 2004,On page(s): 93- 98

[4] Christian Ibars and Yeheskel Bar-Ness**,** *OFDM detection in a macrodiversity system with multiple frequency offsets*, Center for Communications and Signal Processing Research, New Jersey Institute of Technology, Newark, NJ 07102 USA.

[5] Christian Ibars and Yeheskel Bar-Ness, *Inter-Carrier Interference Cancellation for OFDM Systems with Macrodiversity and Multiple Frequency Offsets***,** Center for Communications and Signal Processing Research, ECE Dept., New Jersey Institute of Technology, *Newark, NJ 07102, U.S.A.* Wireless personal communication, Springer Netherlands, Volume 26 , Issue 4 (September 2003), Pages: 285 – 304, Years of publication: 2003

[6] Dukhyun Kim, and Gordon L. St¨uber,, *Residual ISI Cancellation for OFDM with Applications to HDTV Broadcasting.* Dept. of Electr. & Comput. Eng., Georgia Inst. of Technol., Atlanta, GA Selected Areas in Communications, IEEE Journal on Publication Date: Oct 1998, Volume: 16, Issue: 8, On page(s): 1590-1599

[7] Magnus Eriksson, *Dynamic Single Frequency Netoworks,* IEEE Journal on Selected Areas in Communications, vol. 19, no. 10, pp. 1905-1914, Oct 2001.