Capacity, Coverage and Connectivity of Wireless Networks: multi-hop, multi-rate

Report 1

Fei He, Xiang Fu, Yi Xiang Wang

1. Introduction

1.1 Capacity of wireless networks

Capacity is the maximum amount or number that can be contained or accommodated. Different wireless network has its own characteristic of capacity. What we need is to find an ideal wireless network in use whose capacity is as large as better, but at the same time, other demands should be satisfied according to the real conditions. For example, when wireless network is discussed in a metropolis, which means a large scale region, effective control should be taken in consideration to avoid power fading, time delaying, interference. As the nodes in the wireless network are not fixed, in other words, the mobility is related, we will also keep the communications stable without path loss. In addition, security, cost, precision are significant factors as well.

1.2 Coverage of wireless networks

Network Coverage has been one of the key ingredients in wireless networks and has been studied for long. A network with a higher degree of coverage can maintain acceptable coverage in face of higher rates of node failures. Additionally, sufficient sensing coverage can enable the network to monitor the environment with sufficient accuracy, without which may even lead to sensing absents. Coverage of a sensor network reflects how well this network is monitored or tracked by sensors.
In many cases, coverage can be considered as the measure of quality of service of a sensor network..
In another aspect, concerning the physical laws of the energy that decides the performing of wireless communications, network coverage and connection are highly related. Without sufficient connectivity, nodes may not be able to coordinate effectively, that is same inversely cited from the first paragraph.
Classified by the amount of coverage they provide, there are four types of wireless networks, T. A cell-phone network is a wide-area network (WAN) and a business or home wireless network is a local area network (LAN). A smaller network, such as one connecting a printer and a handheld computer, is a personal area network (PAN), and a network between sensors placed around the different parts of a human body is a body area network (BAN).

1.3 Connectivity of wireless networks

Wireless connectivity has developed very quickly in these several years, Wi-Fi, Bluetooth, GPS, Wap, CDMA, 3G, and Radio etc.,all of which are surrounding our life. Above all, connections are most important to the existence value of wireless network, because every element of communication interaction is based on this stage. Despite of some lacks such as safety, high speed and healthy compared with the wired one, the connectivity without linked lines makes a miracle to the information revolution.

Before we begin to talk about the connectivity in wireless network, overviewing previous research makes us ensured that the issue has always been discussed ever since the concept of network (even the wired one) appeared, and because of its feature as an dominating situation in this field, whenever a new concept comes into our mind, it is absolutely necessary to recast interest on the enduring topic. From early context of radio networks to nowadays pop study object, such as ad-hoc, multi-hop or large-scale sensor networks, a lot of attention is paid on the full connectivity of a specific network above with many nodes.

Since connectivity is a quite abstract term, we can regard it to be independent from traffic load in the network. Connectivity between nodes is far more than a link on the physical layer. Whether two connected nodes can communicate with each other at any given moment in time depends on the interference condition which is directly linked to simultaneous communication between other nodes in the network. Due to interference, communication between two connected nodes may drop to lower speeds or even become impossible at certain times. However, in these cases we say that the link capacity is reduced, instead of saying that the probability of connectivity between these two nodes is decreased.

1.4 In a word

Wireless networks consist of a number of nodes which communicate with each other over a wireless channel. The research of wireless networks traced back to about ten years ago. Nowadays, wireless networks have been developed to a new level. Wireless technology is used in most highly populated regions, but there are also a lot of limitations waiting to be solved, such as insufficient coverage, low system capacity, low bandwidth, low transmission rate, high delays, low security, numerous overlapping without agreement, etc. Capacity, coverage, and connectivity of wireless networks are three keys to the answer of high-qualified wireless communication.

2. Related Works

2.1 Capacity Related

Lots of professors and academicians have researched related work about the capacity of wireless networks. We could divide them into different kinds of areas on the topic in brief as follows.

The classic paper made by Piyush Gupta and P.R.Kumar [1] established the capacity of ad hoc wireless networks by analysis about two types of large scale networks, Arbitrary Networks and Random Networks, and concludes that under no interference, the capacity of wireless networks with n nodes whose ability of transmitting are equally W bits per second is O(W/(nlogn)^0.5), and the upper bound of capacity is no more than O(W/(n)^0.5) for Random Networks and

O(W/(n)^1/a) for Arbitrary Networks which will not change with different channel or positions of

nodes.
Another classic one written by Matthias Grossglauser and David N.C.Tse [2] examined the asymptotic throughput capacity of large mobile wireless ad hoc networks, and the results shows that mobility can improve network capacity, though at the cost of increased end-to-end delay, which is actually a great breakthrough different from what people thought previously.
Obviously, these researches as previous are typically considered wireless networks with a single channel, but the results can be applied to a wireless network with multiple channels, if there is a dedicated interface per channel at each node. Pradeep Kyasanur and Nitin H. Vaidya [3] establish the capacity of multichannel networks under arbitrary network setting and random network setting, characterize the impact of number of channels and interface switching delay, and show that in a random network with up to O (log n) channels, switching delay may not affect capacity if multiple interfaces are used. Wei Wu, Sriram Vishwanath and Ari Arapostathis [4] analyze the discrete memoryless and the Gaussian two-user multiple access channel with state and feedback, and prove that additive Gaussian interference that is known non-causally to the transmitter causes no loss in capacity for the Gaussian MAC with feedback. Capacity of ad hoc networks with channel state information is also discussed by Steven Weber, Jeffrey G. Andrews, Nihar Jindal [5].
Security is another important factor to be considered. Vartika Bhandari and Nitin H. Vaidya [6] established secure capacity results for wireless networks with random key pre-distribution, based on past work by us on multi-channel wireless networks with channel-switching constraints
In addition, there are many other reasons that will affect the capacity of wireless networks, and interference is one of them. T. Charles Clancy [7] gives us an interference temperature model as a possible solution to the dynamic spectrum allocation problem.
Dapeng Wu and Rohit Negi [8]propose and develop a link-layer channel model termed effective capacity (EC) to facilitate the efficient support of quality of service (QoS) in next-generation wireless networks which has the features: simplicity of implementation, efficiency in admission control, and flexibility in allocating bandwidth and delay for connections
To sum up, all of these works give us new ideas to further understand the capacity of wireless networks.

2.2 Coverage Related

Researchers generally study network coverage in aspects of algorithmic solutions of information coverage, topological characteristic of network and energy distribution as well. Best and worse case analysis is also a common way to the comparison of networks' coverage. In this paper, we are going to show the ingredients that we have read that seems to be important to this area.
[9] is a classical paper that combines existing computational geometry techniques and constructs such as the Voronoi diagram, with graph theoretical algorithmic techniques. It transforms the continuous geometric problem into a discrete graph problem. In addition, the team studied asymptotic. Paper [10] was the first to identify the importance of computational geometry and Voronoi Diagrams in sensor network coverage while [11] deals with determining the number of observers necessary to cover an art gallery room such that every point is seen by at least
one observer. Coverage becomes a special case of path planning when the geometry of the

environment is known in advance [12].

Reference [13] is cited to define a sensor coverage metric called surveillance that can be used as a measurement of quality of service provided by a particular sensor network, and centralized optimum algorithms that take polynomial time are proposed to evaluate paths that are best and least monitored in the sensor network. Further investigations were made to solve the problem of how well a target can be monitored over a time period while it moves along an arbitrary path with an arbitrary velocity in a sensor network..[14]. Besides, Paper [15] proposes a novel solution to determine whether a sensor network is k-covered. Instead of determining the coverage of each location, their approach tries to look at how the perimeter of each sensor's sensing range is covered, thus leading to an efficient polynomial time algorithm. As long as the perimeters of sensors are sufficiently covered, the whole area is sufficiently covered.

2.3 Connectivity Related

For large-scale ad-hoc networks, especially an unreliable wireless sensor networks, assuming N is the number of nodes in a range-setted area, the capacity is always limited while the density of nodes per area unit becomes large. But on the other hand, the connectivity is guaranteed over more by the increase above: when the number of nodes N tend to an infinite, and the distance R(N), so called the transmission radius of each node, below which nodes can connect, decreases at a rate slower than $\sqrt{\lg(N)/N}$,Gupta and Kumar have proven that all nodes are almost surely connected [17]. In many cases, connectivity is always maintained, but at the expense of a decreased capacity. There is therefore a fundamental trade-off between connectivity and capacity [18]. As some extension work, if we define P(N) as the probability that a node is active at some time T, the conditions for the network to ensure the connectivity of active nodes are of the form $P(N)\,R^2(N) \sim \frac{\log(N)}{N}$. And this means when N is large, even the transmission power can be small, the connectivity with coverage still maintains in the network [19].

However, as the connection between each two nodes is established, especially in wireless multi-hop networking, concurrent transmissions may cause interference. Specifically, in a network, if too many devices transmit simultaneously, the interference caused by these transmissions will prevent an intended receiver from receiving the right signal, in other words, the message is lost. On the other hand, if too few nodes transmit at the same time, valuable bandwidth is wasted and the overall throughput may suffer. Hence, the classic problem faced by any MAC layer or scheduling protocol is that only the adequate number of devices is acceptable. Instead, it is necessary to find the subtle balance, in which a large number of devices transmit in parallel and yet, the interference does not cause messages to be lost [20]. Or we can even use deficient CDMA codes as well as simple TDMA scheme to reduce the impact of interferences and improve the real quality of connectivity [21].

3. Referrence

[1]Piyush Gupta and P. R. Kumar, “The Capacity of Wireless Networks,” IEEE Transactions on

Information Theory, vol. 46, no. 2, pp.388–404, Mar. 2000.
[2]Matthias Grossglauser and David Tse, “Mobility Increases the Capacity of Ad-hoc Wireless Networks,” in Infocom, 2001.
[3] Pradeep Kyasanur and Nitin H. Vaidya, cImpact of Channels, Interfaces, and Interface Switching Delay,” Technical Report, Oct.2006.
[4] Wei Wu, Sriram Vishwanath and Ari Arapostathis, “On the Capacity of Multiple Access Channels with State Information and Feedback,” Technical Report, Jun. 2006.
[5] Steven Weber, Jeffrey G. Andrews, Nihar Jindal, “Throughput and transmission capacity of ad hoc networks with channel state information,” Technical Report, 2006.
[6] Vartika Bhandari and Nitin H. Vaidya, “Secure Capacity of Multi-Hop Wireless Networks with Random Key Pre-distribution,” Technical Report, Dec. 2007.
[7] T. Charles Clancy, “Achievable Capacity Under the Interference Temperature Model,” FCC, 2003.
[8]Dapeng Wu and Rohit Negi, “Effective Capacity: A Wireless Link Model for Support of Quality of Service,” IEEE Transactions on Wireless Communications, vol. 2, no. 4, pp.630-643, July. 2003.
[9] Coverage problem of sensing Coverage Problems in Wireless Ad-hoc Sensor Networks
Seapahn Meguerdichian1, Farinaz Koushanfar2, Miodrag Potkonjak1, Mani B. Srivastava2
1 Computer Science Department, University of California, Los Angeles
2 Electrical Engineering Department, University of California, Los Angeles
[10] Personal communication with J. Agre, Rockwell Siences Center.
DARPA Program Review Meeting, Feb. 2000.
[11] M. Marengoni, B.A. Draper, A. Hanson, R.A. Sitaraman, “System
To Place Observers On A Polyhedral Terrain In Polynomial Time,”
Image and Vision Computing, vol.18, pp. 773-80, Dec. 1996.
[12] C. Hofner, G. Schmidt, “Path Planning And Guidance Techniques
For An Autonomous Mobile Cleaning Robot,” Robotics and
Autonomous Systems, vol.14, pp. 199-212, May 1998.
[13]S. Meguerdichian, F. Koushanfar, M. Potkonjak, and M. B.
Srivastava. Coverage problems in wireless ad-hoc sensor networks. In IEEE INFOCOM, pages 1380–1387, 2001.
[14]S. Meguerdichian, F. Koushanfar, G. Qu, and M. Potkonjak.
Exposure in wireless ad-hoc sensor networks.
ACM Int’l Conf. on Mobile Computing and Networking (MobiCom), pages 139–150, 2001.
[15]The Coverage Problem in a Wireless Sensor Network
Chi-Fu Huang National Chiao-Tung University
Department of Computer Science and Information En2gineering
Yu-Chee Tseng National Chiao-Tung University
Department of Computer Science and Information Engineering
Reference
[16]Integrated Coverage and Connectivity Configuration in
Wireless Sensor Networks

Xiaorui Wang, Guoliang Xing, Yuanfang Zhang*, Chenyang Lu, Robert Pless, Christopher Gill

Department of Computer Science and Engineering Washington University in St. Louis
[17] P. Gupta and P. R. Kumar, “The capacity of wireless networks,” IEEE Transactions on Information Theory, vol. IT-46, pp. 388–404, March 2000.

[18] O. Dousse, P. Thiran. “Connectivity vs Capacity in dense ad hoc networks."”Proceedings of IEEE INFOCOM '04.

[19] S. Shakkottai, R. Srikant, and N. Shroff, “Unreliable sensor grids: coverage, connectivity and diameter,” in Proceedings of the IEEE INFOCOM, 2003, pp. 1073–1083.

[20] T. Moscibroda and R. Wattenhofer, “The Complexity of Connectivity in Wireless Networks,” In Proc. of the 25th IEEE INFOCOM, 2006.

[21] O. Dousse and F. Baccelli and P. Thiran. “Impact of Interferences on Connectivity of Ad Hoc Networks.” ACM/IEEE Transactions on Networking, to appear.