A White Paper on the use of Mesh Networking Technology as part of a Cognitive Radio Technology.

Submitted by MeshNetworks
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Executive Summary

This white paper has been prepared by MeshNetworks to provide the Federal Communications Commission with information on the use of Ad Hoc networking technology in a Cognitive Radio. It is in response to the FCC Docket 03-108 (December 30,2003) entitled "*Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies*". Specifically it addresses section D.3 Mesh Networks. This white paper provides an overview of mesh networking technology, a description of how it can be applied to improve spectrum utilization, some of the unique and new applications a mesh network can enable and discusses some of the ways that FCC policy can facilitate the use of mesh networking in achieving he objectives of Docket 03-108.

Attributes of a Mesh Network

Mesh Networks are also known as Mobile Ad Hoc networks, Multi Hop networks, Self forming Self healing networks, Cooperative Networks and Peer to Peer Networks. All are predicated on a new network technology and architecture. They are equally applicable across all frequency and modulation techniques and contrast specifically to the classic hub and spoke architectures of a cellular system or 802.11 AP network. They are generally applied to mobile networks, but have attributes that are equally applicable to fixed wireless networks. There is a misconception that the network topology and routing protocols of the wired internet can be overlaid on a wireless mesh network but the relative instability of a wireless physical layer makes this impractical.

Mesh networks were originally conceived during Packet Radio experiments funded by the Department of Defense's Advanced Research Projects Agency (DARPA) more than 20 years ago, and have since been deployed with great success by the US military. This technology has recently become commercially viable and an extremely attractive solution to fulfill the ever growing demand for high bandwidth, low-cost wireless solutions.

A mesh network is a collection of mobile terminals (e.g. handheld devices, mobile phones, automotive telematics systems, etc.) that communicate directly with each other without the aid of established infrastructure (figure 1). Through multi-hop connections, the terminals act as routers/relays for each other and extend the range and coverage (figure 2) of communications between parties. Traditional wireless networks, such as cellular and WLAN, rely on single-hop architectures with the control residing in a centralized location and therefore no peer-to-peer communication. There are expectations that mesh networks will require less power while providing higher capacity and robustness, without significant infrastructure investments. This leads to the belief that ad hoc wireless systems can be successfully deployed at a much lower cost than a traditional wireless topology. However, wireless mesh networking is more complex than traditional wireless systems, and while it solves a number of traditional network shortcomings, it comes with its own set of technological challenges that must be solved.

Some industry cynics claim that ad hoc wireless networks will not scale, will not provide the required throughput, are not secure, and will deplete the batteries of all the host devices thus making the technology commercially unfeasible. Contrary to that viewpoint, a growing number of commercial companies are developing and deploying products based on ad hoc wireless technology, which is indicative that these issues can and will be successfully resolved. In addition to these companies pioneering the technology for commercial use, the industry is striving to standardize protocols and architecture solutions.

Taken individually, a case can be made for and against each claim. Performance of the technology in real life, however, is dictated by the overall system architecture and mechanisms that balance these conflicts in the most efficient manner. The real attraction of a mesh topology is its ability to significantly improve the capability of any RF modulation scheme by:

- Requiring less power
- Having the ability to be rapidly deployed and reconfigured
- Providing better frequency reuse
- Not requiring Lines of Sight (LOS)
- Being able to load balance around congestion
- Providing redundancy to deal with failure
- Requiring less centralized infrastructure
- Providing capacity and scalability improvements

Reduction of power is achieved by choosing to transmit over two short distances versus one longer one. This translates into either a lower transmit power, or a higher data transmission speed. Either one will limit the total energy transmitted. This can be demonstrated simply with an 802.11b network by placing a node half way between a transmitting node and the AP. If the transmitting node is only able to maintain a 1mbit data rate directly, the 7dB of gain achieved by halving the transmit range results in the data rate improving to 11mbits. The result of these lower powered hops is that the devices achieve higher system throughput and create less interference into their environment (figure 3). Because higher data rate transmissions require more power multi hop networks are the only way to overcome range limitations in power limited systems. Power limitations are real. Defined either by the battery life of a device or the regulatory requirements for public health and safety. Reductions in power are manifested both by better battery life but also, more importantly, by less interference which equates to better frequency reuse.

Because wireless ad hoc networking requires no infrastructure, the terminals must cooperate to organize into a network resolve contention for the available bandwidth and discover and maintain routes amongst themselves. For some applications this attribute makes the use of a mesh network viable, where the cost of an infrastructure, or lack of any pre-existing infrastructure would otherwise make a network unworkable. This permits a mesh network to be rapidly deployed with very little planning. Adding nodes or removing nodes is generally handled without any centralized control. This capability, that exists in commercial MeshNetworks deployments today. Is key component of the CR definition. The radios already have the capability to discover each other, interact with each other and evaluate the RF environment they are operating in. The one, critical, component missing from these solutions today is they lack the ability to determine how much interference they add to the environment when they transmit (interference temperature analysis).

A major challenge for the traditional cellular networks is the requirement to build excess capacity to deal with the mobility of the users. As users migrate from the suburbs in the morning the demand in the city increases. The network has to be engineered to support this although the capacity remains unused at nights and weekends when the users return home. A mesh network can route around congestion, or failure for that matter, by way of having the intelligence at the edges to choose from multiple routes to the destination. In addition adding a user to a cellsite coverage area reduces the capacity for all other users in a mesh network adding user has the potential to increase the capacity of the network.

System Efficiencies of Mesh Networks

The previous section discussed the basic attributes of a mesh network but the benefits can be significantly greater when applied to the system. With the ability for nodes to talk directly to each other there is no burden on the infrastructure when the do not need it. In addition there is likely only half as much requirement for resources such as RF channels when they can talk directly. In the case of the user too far from the AP the benefit of relaying the traffic improves the availability of the AP for all users. The capacity gains are somewhat counter intuitive. The first reaction of a user is to ask why they should share their nice 11mbit link with someone else. The inference being that their own throughput will be degraded by doing so. In fact the opposite is true. The AP is a shared resource and if I can help get someone else's packets through quicker then I free up more time for me to use it. Figure 5 shows a simple scenario where 1 user is close to the AP and able to communicate at 11mbits/sec where as the second user is only able to connect at a 1mbit data rate because of the distance from the AP. If both users place a constant load on the AP the AP will max out at 1.1mbits/sec of throughput. This is because the distant user throttles back the closer user. Figure 6 repeats the test with the distant user hopping through the close user and the capacity of the AP goes up to 1.5mbits/sec a 35% increase[1]. This improvement is realized by the utilization of least energy and power control considerations in

[1] This scenario was measured using Opnet with 802.11 and a DV routing algorithm as well as validated with a commercial 802.11 radio network.

the routing algorithm. The amount of the increase will be somewhat dependent on the topology of the users, the fairness algorithms and the overhead of the routing protocol but we have seen between 15% and 40% in different scenarios.

Policy Positions on Mesh Networks

Paragraph 77. A mesh network, by definition, requires a capability that fits within the broad FCC definition of an SDR or cognitive radio. As stated earlier a mesh network is radio agnostic and so in it's simplest sense a mesh network is not a radio technology and therefore not under the prevue of the FCC. Mesh networks can be deployed today under current FCC regulations such as FCC part 15 applied to the 2nd ISM band. There are however many aspects of FCC regulation and policy that could make it possible to create more optimal mesh networks.

Paragraph 78. Many mesh networks today are running very successfully in unlicensed spectrum such as the 2nd ISM band. Here they can exploit the low power requirements and wide channel bandwidths to good effect. Mesh networks do not have to be implemented in unlicensed spectrum and in some cases would benefit from operation in licensed spectrum. As such this paper focuses on future regulation and policy as opposed to trying to retrofit mesh networks into existing bands.

Experimental license band.

Today most active mesh networking development is done in the 2nd ISM band and the U-NII bands. While these bands are acceptable they are actively used by many other groups with whom the mesh network must co-exist. Because of the experimental nature of many mesh networking technologies a dedicated band of spectrum for the use of progressing and protecting the US lead in the field may be in the best interests of the industry. Improving their competitiveness in the global market. Today a good mobile wireless rule of thumb is 1bit/hertz. With this in mind contigious spectrum of 5Mhz is a realistic minimum for a network but to make efficient use of the spectrum and allow for reasonable reuse or multi-channel MAC technologies 40-80Mhz is a realistic segment.

Focus on interworking and interoperability.

As no spectrum or modulation is a panacea for wireless communications it is inevitable that there will be multiple technologies deployed for the foreseeable future. Currently deployed cell networks will likely exist for a long period so there are several interworking and interoperability issues to be addressed. First is the interworking and interoperability of multiple mesh networks. Questions arise about how they can exist next to each other (which one should I join)? How do they merge and split? How do they prioritize traffic? In the case of a mesh trying to interwork with a cell network the question of which to use? How to migrate, and when, from one to another? Are examples of the issues.

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A theoretical promise of a mesh network is infinite capacity within a finite amount of available bandwidth. The reality is that such a capability has huge complexity and many of the issues related to the implementation are not yet understood. So any policy decisions should recognize near term limitations. It is certainly true that the promise hold more true in licensed spectrum where interferers can be controlled than in unlicensed spectrum where they cannot.

Paragraph 80
Reliability in a mesh is provided by distributed redundancy, similar to the wired internet. There is an implication that the deployment of the mesh has addressed this capability. In an ideal situation each node would have 2 or 3 distinct routes to a destination such that failure of a single node or group of nodes would not remove the ability for the node to communicate. The more intelligence at the edge of the network the more a node can respond to failure, or congestion, and decide that it should route around it and be able to determine how to route around the condition. From a deployment perspective infrastructure nodes need center to center coverage, as opposed to the edge to edge coverage typical in a cellular network.

In Summary. MeshNetworks applauds the efforts of the FCC in the whole arena of Cognitive radio. MeshNetworks believes that ad hoc networking is a critical component of this initiative and will be very willing to assist in the ongoing efforts to improve the regulatory environment in this regard.