

# Large Scale Cognitive Wireless Networks

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*Abstract*— we introduce a demonstration of the *large scale cognitive wireless networks*, where it opportunistically utilizes network resources including both spectrum bandwidth and radio (wireless station) availability, so as to realize reliable wireless communications. Specifically, the proposed demonstration deals with an application of wireless mesh networks for broadband wireless Internet access, supporting guaranteed real-time services of voice or multimedia. A number of advantages of the cognitive networking can be shown by the proposed demonstration, including dynamic network operation and deployment; better (opportunistic) network resource utilization; guaranteed multiple-hop QoS (Quality of Service) for voice/video; and robustness to interferences. The performance of the network could therefore reach its instantaneous maximum.

## I. INTRODUCTION

The capacity of wireless networks is determined by the occupied spectrum and the number of radios. In general, the theoretical transport capacity [1] is determined by the order of  $O(B \cdot N)$ , in terms of *bit meter/sec*, where  $B$  is the spectrum bandwidth, and  $N$  is the number of radios. Although the theory pronounces promises to build large-capacity wireless networks, since both  $B$  and  $N$  can be large in a large-scale network with unlicensed bandwidth, practical solutions to achieve this have been unavailable. This can be primarily due to the dynamic availability of both types of resources: 1) random spectrum availability being introduced by interferences (e.g., in unlicensed bands); 2) random radio availability being introduced by dynamic traffics (congestions) and other factors such as radio failure.

For example, wireless mesh infrastructure has been considered as a cost-effective solution to broadband wireless Internet access. Evidences are such that municipal WiFi mesh networks are rolling out in a number of cities across North America, which are able to provide for basic Internet services to general publics in municipal areas. However, the Quality of Service (QoS) of wireless dataflow, such as throughput, end-to-end delay, and delay jitter, could degrade fast with the number of wireless hops. Therefore, the network engineering must limit the number of wireless hops by installing more gateways (i.e., stations with fiber/cable network backhubs) in network. This introduces high costs to current mesh infrastructures, e.g., including the deployed municipal mesh, which have resulted in their limited service coverage. Moreover, no reliable QoS could be supported over multiple

wireless hops by state-of-the-art technologies; hence real-time services such as voice and video could not be available.

The demonstration shows that the technology of large-scale cognitive wireless networks [2] can resolve aforementioned limitations, by the opportunistically utilization of networks resources, including both spectrum bandwidth and mesh radio (station) availability.

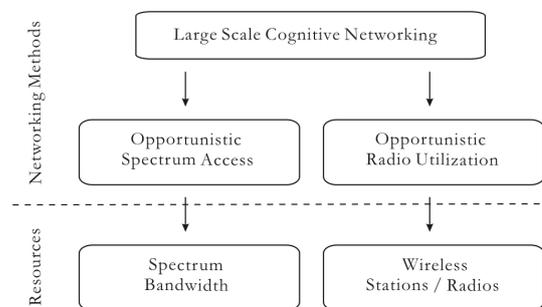


Figure 1: Concept of Large Scale Cognitive Networking

## II. DESCRIPTION OF THE DEMONSTRATION

The proposed demonstration is a prototype based on the large-scale cognitive networking technology, for the wireless mesh infrastructure supporting seamless voice and video services (i.e., via wireless Internet). Although a commercially available solution is based on WiFi radio/access (IEEE 802.11 [3]), this proposed demonstration prototype is implemented with Zigbee (IEEE 802.15.4 [4]) radio, which contributes to a practical demonstration space requirement due to the much smaller radio range. There are no significant technical differences between the wireless mesh implementations with WiFi and Zigbee radios.

Shown in Figure 2, the mobile user is a laptop plugged with a radio board; mesh stations are built by the stack of three radio boards, where the bottom one is programmed as an access point of the access networks, the upper two are combined as a cognitive radio platform for the wireless mesh networking, with one data transceiver and one pilot tone transceiver, respectively; the gateway is another laptop connected to another cognitive radio platform for the mesh networking, i.e., with a stack of two radio boards. The maximal air-interface radio rate is  $250kbps$ , whereas the radio

transmitting power is programmed to its lowest level  $-25\text{dBm}$ , giving the radio range of about only 1-2 meters. *Three* independent channels in  $2.4\text{GHz}$  band are dynamically accessed with the cognitive radio platform.



Figure 2: Pictures of the Prototype

In the demonstration, a mobile user can initiate a live audio session ( $32\text{Kbps}$  ADPCM), and send it to a gateway, via the associated access network, as well as the described opportunistic mesh. The transmitted audio session can then have live playback at the gateway. This prototype can therefore demonstrate the suggested technology highlights. Specifically, non-interrupted audio can be shown with seamless user mobility under arbitrary (dynamic) network formation, i.e., ad hoc placements of the mesh stations. The robustness can be demonstrated by the “drop-and-play” nature of mesh stations, where instantaneously removing of any one mesh station does not degrade on-flying audio quality. The scalability can also be demonstrated by the fact that the more mesh stations we instantaneously place in the network, the better they can work for the user's experience. Moreover, since the prototype performs well in the most crowded  $2.4\text{GHz}$  band, where external interferences are intensive, e.g., from other adjacent WiFi hot zones, it can open excellent business opportunities for cost-effective mesh network solutions, with the value-add of real-time service support.

### III. TECHNOLOGY ADVANTAGES

Some technical advantages of the large-scale cognitive networking are summarized in the following:

*Dynamic network operation and deployment:* since no deterministic network topology is maintained, the dynamic “drop-and-play” nature offers the potential of vast cost-saving in infrastructure engineering. For example, in large-scale municipal mesh blanketing city areas, the installation of mesh stations/radios does not necessitate expensive planning and calibration, and multi-tier new deployments guarantee improved network capacity.

*Better network resource utilization:* theoretical wireless network capacity is decided by network resources, which is the multiplication of two factors including spectrum bandwidth and the number of stations/radios. Since both types of resources cannot be predetermined subject to volatile unlicensed bands and dynamic traffics, the developed technology offers the means of better (opportunistic) network

resource utilization, so as to approach the information-theoretical capacity.

*Robust to interferences:* due to the opportunistic utilization of spectrum availability, the network is very robust to interferences which can be substantial in unlicensed spectrum bands (e.g., ISM bands). Viable operation within unlicensed bands brings large free bandwidth, which results in large network capacity with virtually zero cost.

*Supporting scalable multihop QoS:* guaranteed dataflow QoS can be supported over multiple wireless hops, in terms of throughput, end-to-end delay, and delay variance. Therefore, operators only need to ensure sufficient network resources being deployed to support their subscribers, where the resources, e.g., radios or wireless stations, can be deployed with low cost.

*Compatible with current industrial standards:* The proposed technologies are compatible with all established access-network standards, especially the family of WiFi (IEEE 802.11) standards. The protocol establishes a cognitive wireless link layer which can be seamlessly integrated with Internet protocols (IP) and most physical layer standards. Therefore, related networking equipments can also be well integrated with existing infrastructures.

### IV. CONCLUSION

A demonstration of large scale cognitive networks is introduced, and a number of technology advantages are shown. The technology can be contributing to applications of large scale wireless systems, including for example: wireless mesh networks for broadband wireless Internet access; real-time wireless sensor networks; and emergency wireless ad-hoc networks.

### REFERENCES

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