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Smart Physical Layer Based Directional Communication Networking

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Abstract

In this paper, a smart physical layer based directional communication networking approach is described. It consists of "smart nodes," equipped with multiple directional antennas and propagation modeling capabilities. This approach brings more "intelligence" (digital logic) in the physical layer to enable full directional communication networking operation without requiring changes in the upper OSI layers. Smart nodes consist of six-sectors, each having a scanning array for user discovery and a dynamic beamforming array for maintaining communication with users. Procedures are developed to enable seamless full-directional link between mobile users and smart nodes, within WiFi and LTE set standards. Simulations are performed using Matlab, and obtained results show successful tracking and continued maintenance of high data rate communication with mobile users.

1. Introduction

There is significant interest in utilizing directional antennas such as those developed in [1] for point-to-multipoint directional networking. Directional antenna advantages include security, reduction in interference, as well as economical coverage and energy savings in sparsely populated areas. Directional antennas face a challenge of their own, i.e. the deafness problem [2] which has not been adequately addressed by prior work without making modifications in the MAC layers of the radio being used.

This paper describes a smart directional communication networking approach being developed by our group [4]. It consists of interconnected "Smart Nodes." These nodes are equipped with multiple high gain, narrow beam, directional antennas (such as [1]) and digital beamforming capabilities for user discovery as well as for maintaining continued communication. To ensure that full-directionality is achieved, algorithms and procedures are developed that bring intelligence to the Physical Layer and conform to the timing standards of the wireless radio being used (such as LTE and WiFi).

This paper is divided as follows: Section 2 describes the smart nodes while Section 3 discusses their networking aspects. Section 4 provides a brief highlight of the simulation results and Section 5 concludes the paper.

2. Description of Smart Nodes

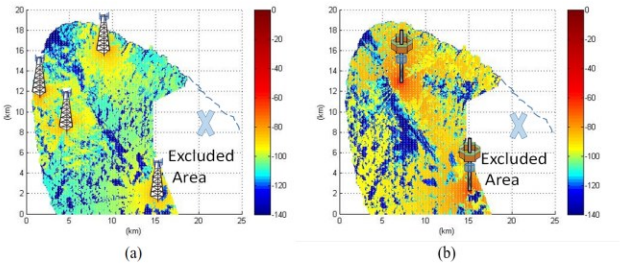
A smart node provides directional coverage using six sectors, each of which is equipped with an antenna array for communications. Two additional antenna arrays are also used, one for a scanning beam and the other is for node-to-node link. The smart node uses the scanning beam to scan for new users, and the communication beam to communicate with discovered users. The node-to-node link beam is used to provide point-to-point connections between smart nodes as well as to the core network.

The smart node sweeps its scanning beams at discrete angles and wait in each position (100 ms for WiFi and 40 ms for LTE), to facilitate user discovery. Using Angle of Arrival (AoA) from the scanning beam, a communication beam is formed in the users' direction. AoA estimation is performed via standard techniques such as MUSIC or (the faster, single-snapshot based) Matrix Pencil method, after which the digital beamforming weights are adjusted accordingly and data transferred to the beamformer in the communication array.

3. Communication Network Design

Tools developed in [5, 6] are used to acquire path gain/loss data from geospatial assets (such as Google Earth). Genetic Algorithm (GA) uses this data to optimally place nodes in a given area. Maui Island, Hawaii and Kohala Region of the Big Island, Hawaii are used as two test areas for demonstration. Simulations were conducted to compare the cellular coverage offered by omnidirectional base stations (with a gain of 5 dBi) with that of smart nodes, equipped with directional antenna arrays (with array gain of 19 dBi). Figure 1 shows the comparison (Kohala region of the Big Island, HI), demonstrating that two smart nodes can provide same coverage as four omnidirectional nodes.

Besides the above described optimized smart nodes placement using propagation modeling assets, the remaining networking connectivity is modeled and simulated using traditional tools such as Network Simulator 3 (NS3).



	# of Nodes = 1	# of Nodes = 2	# of Nodes = 3	# of Nodes = 4
Omnidirectional (5 dB gain)	57 %	69 %	78 %	83 %
Directional (19 dB gain)	67 %	81 %	91 %	95 %

Figure 1. Kohala region of the Big Island, HI: (a) four Omnidirectional base stations, (b) two smart nodes.

4. WiFi and LTE Simulations

Smart node simulations using 8-element scanning and communication arrays, are performed on a setup of mobile users that communicate with the node on WiFi and LTE radios, using Matlab toolboxes. Figure 2 shows an example that demonstrates the multi-beam capability of the smart nodes, over WiFi radios. In Figure 3, user mobility simulations are shown for smart node implementation over LTE radios.

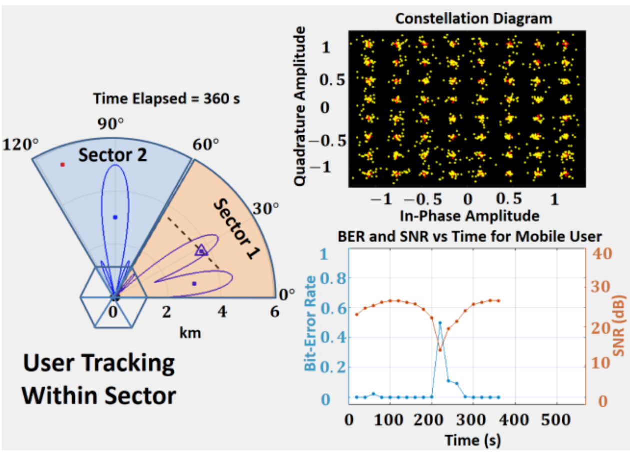


Figure 2. Smart Node WiFi simulations.

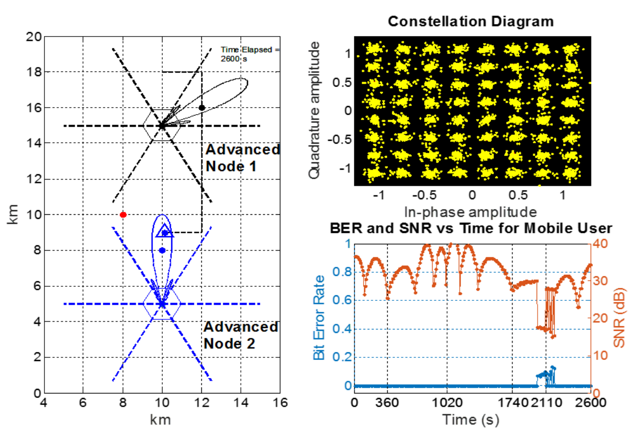


Figure 3. Smart Node LTE simulations.

4. Conclusion

A smart directional communication networking approach is proposed and its integration with the LTE and WiFi is simulated and evaluated. The approach is based on developing advanced capabilities in the physical layer including propagation modeling and sets of directional antennas as well as enhancing the DSP and computational resources in the smart base station. Three antenna arrays are used in each smart node for mobile user discovery, a dynamic beamforming array for communication with mobile users and an adaptive array for node-node and node-core network connectivity. Developed approach conforms to the timing requirements of the LTE or WiFi radios. Simulations and the trade-offs associated with smart nodes will be discussed and presented at the conference.

5. Acknowledgements

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6. References

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