

## Research Directions for Fourth Generation Wireless

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Though taxonomies can be imprecise, wireless communications systems are frequently classified by generation. First generation wireless denotes voice-only analog cellular systems. Second generation wireless systems ushered in digital transmission technologies to meet the capacity demands of burgeoning voice services. The coming third generation differs from second generation systems more in the ability to integrate voice and data applications than in radical differences in transmission technology. Though widespread deployment for third generation systems awaits widespread demand for wireless mobile data, we confidently predict that the Field of Dreams principle<sup>1</sup> will continue to apply to the wireless industry. In this paper, we indulge in speculation on how these yet to be deployed systems may evolve, and more interestingly, the technologies that will be required to support the 4<sup>th</sup> generation systems that lurk in the cornfields of the future.

We presume that if 3<sup>rd</sup> generation systems successfully integrate voice and data, consumers will demand ubiquitous access those new services, regardless of the supporting infrastructure available at a given time and location. As a result, the primary advance of 4<sup>th</sup> generation wireless systems will be the seamless integration of wireless networks. Today's fixed internet user accesses the network via a path that may involve many nodes supported by many different organizations, dynamically negotiating for use of those facilities in a

manner completely transparent to the end user. In a similar manner, wireless devices will obtain the desired network connectivity in the most cost-effective manner, whether that might be through one of several competing cellular networks or via a multi-hop wireless network. This standard for flexible connectivity will create a need for new business models, and new wireless technologies. We explore several required technologies in this paper.

First, the need to interact with multiple wireless services using multiple transmission standards will create an unprecedented need for flexible radio capabilities. As a result, software radio technology that has long been reserved for large base stations will find application within mobile devices. In order to make this transition a reality, new approaches to power consumption will need to be developed. These approaches, which we will explore in more detail in the full paper, may include efficient configurable computing devices and low power analog-to-digital and digital-to-analog conversion. They may also include new low-power signal processing algorithms design specifically to minimize requirements for computational precision.

Second, emerging wireless applications may create new opportunities for previously unused signal processing approaches. The current model for data applications follows the stereotype of an Internet surfer in which data flows asymmetrically from the network to the user. As a result, it is anticipated that forward link capacity will be the initial bottleneck in third generation systems. It is not clear, however, if human users by

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<sup>1</sup> "If you build it, they will come"

themselves will generate the traffic needed to fill the wide data pipes of third generation systems. However, when automated devices, ranging from smart sensors to vending machines are integrated into the wireless network, wireless data traffic may soar. For such wireless devices, traffic may be balanced along the forward and reverse links or even biased asymmetrically in favor of the uplink. As a result, signal processing technologies that hold the potential to improve the capacity of the uplink to a base station, such as multiuser detection, may be fully exploited in future wireless systems.

Finally, the fluidity of wireless networks may require new network architectures that move away from the need for fixed cellular infrastructure. Given the limited availability of spectrum, it seems likely that fixed communication links will always have higher capacity than their wireless counterparts. Wireless networks will always be structured in such a way as to route information

to the wired backbone network via the shortest path. However, if coverage is to be ubiquitous, the shortest path will not necessarily be via a single transmission to a fixed cell site. Increasingly, if network connectivity is to be maintained under all circumstances, packets of information may flow to and from wireless devices over multi-hop peer-to-peer networks. For the last decade, signal processing research has focused on optimizing wireless links in the context of a cellular network. The widespread use of packet data networks to augment the cellular backbone will create a need for new types of signal processing techniques. This includes low complexity interference mitigation techniques that cope with interference of from both known and unknown sources. This may also include rapid packet synchronization techniques, which allow data to be transmitted and routed on a connectionless packet by packet basis without lengthy call setup procedures.