

Architectural Implications of Multi-Dimensional Scalability in Wireless Networks

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Future wireless networks must be “scalable” in multiple dimensions: number of nodes and subnets, diversity of node technologies and applications, physical coverage of subnets, and node density. This multi-dimensional scalability creates numerous challenges in the areas of network performance and management. These challenges are exacerbated by the properties of the wireless transmission medium: wireless networks share a scarce resource (the spectrum), which results in bandwidth contention and RF interference between individual nodes and subnets, and opens the door for novel security threats. Furthermore, future wireless network architectures must accommodate different types of deployments. Besides professionally-managed campus networks, we are seeing a rapid growth in “chaotic” wireless networks that are setup by non-experts [1]. These chaotic deployments range from single-AP home networks to small multi-AP deployments, e.g., in malls. In this paper, we look at the implications of multi-dimensional scalability for both the architecture of the wireless network and its interface to the wired backbone, focusing on unlicensed spectrum, where we have seen the most growth and innovation.

It is interesting to compare the multi-dimensional scalability features of wireless networks with the Internet features. While both must scale both in terms of numbers of nodes and subnets, they differ substantially in several other aspects. First, since the wireless spectrum is a *limited resource*, there will be significant pressure to use it efficiently. Of course, there is also economic pressure to use wired networks efficiently, but wired capacity can typically be increased fairly easily by adding fiber. Second, while wired subnets are well isolated from each other (management, performance, snooping ..), such *isolation is lacking* for wireless subnets sharing spectrum in the same physical area. Some applications (e.g. cellular providers, broadcast TV, ..) are isolated since they have licensed spectrum, but this approach often leads to inefficient spectrum use [2]. Lack of isolation between subnets will affect manageability, performance, fairness, and security. Third, while there is some diversity in Internet nodes and applications, from the perspective of the network, the nodes have been largely “homogenized” by the ubiquitous use of IP and TCP/UDP. In contrast, wireless networks will be *incredibly diverse*, adding complexity to both network and traffic management. For example, nodes will range from “smart” dust to powerful wireless multimedia servers. Applications will range from sensors that occasionally send a few bits to multimedia servers that send high-bandwidth video stream. Finally, *management and security* are significant challenges even for wired networks, in part because these were not primary goals of the original Internet architecture since it targeted a more collaborative environment. Wireless network properties such as chaotic deployments, spectrum sharing, and mobility will add considerable complexity.

While many of the techniques developed for the Internet (modularity, hierarchical routing, protocols, ...) will also be useful for future wireless networks, the unique properties of wireless networks will affect their architecture. Here we focus on five topics: subnet interoperability, dynamic spectrum sharing, management and security, quality of service and fairness, and support for novel services.

Subnet Interoperability - In the Internet, interoperability between nodes and subnets is achieved using IP, the “language” that (originally) provided universal connectivity. Future wireless networks will differ in two ways. First, universal connectivity is not a requirement, e.g. there is no need for temperature sensors to talk directly to multimedia servers; note that universal connectivity also is no longer a feature of today’s Internet. As a result, many wireless subnets will not be able to directly communicate – communication will be indirectly through application level servers. This will result in a lot more diversity in both communication protocols and addressing. On the other hand, the spectrum sharing in wireless networks will require interoperability at the physical and MAC layers (e.g. through etiquettes and shared control protocols), so subnets can coexist and share spectrum resources efficiently.

Dynamic Spectrum Sharing - Even though the spectrum is scarce shared resource, it is currently not used efficiently, both for regulatory and technical reasons [2,3]. New technologies such as software

radios and spectrum-agile devices combined with changes in spectrum use policies will open the door for much more efficient wireless communication. These technologies will create more dynamic wireless networks in which users must be able to negotiate access to spectrum and must be able to switch between frequencies and protocols. Changes will also be needed in spectrum use policy and business models. This spectrum-agile network infrastructure can be viewed as a sophisticated physical and MAC interoperability layer that is much more efficient than what is in use today.

Management and Security – The most direct way to sustain the rapid deployment of different types of wireless networks while maintaining performance (efficiency, security, ..) is to make wireless networks self-managing and self-securing, and many aspects of management and security can be fully automated (e.g. low level configuration). For higher level management tasks, the challenge is to come up with appropriate abstractions that allow both experts (campus) and non-experts (chaotic) to configure management and security. Diversity both at the node (technology, power, ..) and subnet (node count, physical coverage, mobility patterns, ..) level add complexity since management and security solutions must work across a very large design space, e.g. users must be able to roam inside a large campus deployment but also “across” many small subnets. Note that wireless technology can also help address challenges, e.g. wireless nodes can cooperatively identify and localize ill-behaving or malicious nodes.

Fairness and Quality of Service - Spectrum sharing adds considerable complexity to the wireless resource allocation problem. For example, for users with a small number of nodes, there rarely is a reason to reduce transmit power, but high power causes interference for other users and reduces network capacity. In general, there is a tension between cooperation (to maximize performance for a set of nodes) and competition (to gain in performance relative to other nodes). This tension will play out differently in different environments, e.g. large campus versus small chaotic deployments. We will need incentives mechanisms that will encourage node behavior that helps overall network performance and means for enforcement. Applications with stronger QoS requirements create an even more challenging problem, e.g. how can we assure that a user’s random traffic does not disrupt the wireless television of a neighbor. More heavy weight mechanisms (e.g. connection-based protocols, reservations, ..) may be needed.

Supporting Novel Services - Finally, a ubiquitous wireless infrastructure is likely to stimulate the deployment of novel services. One example is localization in which nodes use information about wireless within range to find out where they are. Another example might be “nano ISPs”, where the residential access points can be used by roaming users, for a small fee. Other services are likely to emerge. Such new services will require new interfaces and protocols that can be used to securely access the wireless networks. We also must consider the implications of these new services for network management and security, and we will need new business models that can be used for these services,

Another interesting question is how the multi-dimensional nature and wide-spread deployment of wireless networks will impact the wired network backbone. Since many wireless nodes will be part of isolated subnets that might not even use IP, the direct impact may in fact be limited. It is more likely that new services that are enabled or required by wireless and mobile networks will change the types of services that users expect from the network, thus indirectly impacting the backbone. For example, there will likely be an increased demand for features such as roaming and support for multimedia flows. Support for these features will not be contained in the wireless subnets but will reach into the backbone.

References

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