Innovation in Wireless Technologies

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INTRODUCTION

There is no doubt that wireless communication technologies have been one of the most interesting innovation fields in the telecommunications industry in recent years. The spectacular rate of innovation in this field has enforced the vision of ubiquitous connectivity: the vision of a world where every human being and every electronic device, from high-end supercomputers to tiny sensors of temperature in your car, can talk to each other through a dense web of communication links. A vision of this kind, although more "human-centric," is proposed, for example, in the "Book of Visions" (2001) published by the Wireless World Research Forum. Of course, wireless communication technologies are instrumental in accomplishing this vision, as we cannot possibly imagine to connect everything by means of cables. Moreover, wireless communications offer the advantage of supporting mobility even at high speed.

The goal of this short paper is to propose one possible explanation why wireless technologies have shown such a dramatic innovation rate, and to overview some of the main and most recent technology achievements in this field. We will see that innovation is fostered mainly by freedom to experiment, and that countries offering such freedom, by means of wise regulation, can benefit most of these innovations. Wireless technologies, in fact, have a number of features which make them the best candidate solution for developing countries wanting to create a communications infrastructure with low costs and in a short time frame.

One of the main features of wireless technology can be summarized in one word, *freedom*. Freedom, to some extent, from physical constraints, as there's no need of laying cables through land, roads and buildings, from cost constraints, as most of the times the cost of a wireless infrastructure is significantly lower than that of a wired one, from time constraints, as usually wireless networks can be deployed in a very short time-frame compared to wired infrastructures, from location constraints, as wireless connections can be established potentially everywhere, even in motion, finally, and most significantly for this discussion, in some cases freedom from access constraints, as some frequency bands have been wisely set aside by national and international regulatory administrations to be used as a "spectrum commons" (Lessig, 2002). These bands, such as the 2.4 GHz "industrial, scientific and medical" (ISM) band, are allocated for license-exempt use, meaning that you don't need to ask permission to anybody for using the spectrum. "Users in these bands are liable for interfering emissions they cause, but are not protected from interference from others. Significant incentives are therefore created for users to deploy innovative systems" (Lie, 2004, p. 16) which can minimize interference between different transmissions, as well as optimize the co-existence of many different wireless systems. Moreover, the freedom of access to spectrum has fostered innovation, as there's no administrative or market restriction for innovators to experiment.

Lessig (2002) argues that the staggering innovation fostered by the Internet was mainly due to its character of openness, neutrality and freedom of access. In much the same way, "spectrum commons" have favored innovation at the physical layer, by giving innovators the right to design, implement and deploy innovative systems without asking permission from anybody. Most of the recent technological innovations have been designed to operate in license-exempt bands. On the other hand, if spectrum policy had an impact on the innovation rate of the wireless world, in turn technological advances and innovative services are changing the way regulatory administrations allocate and manage spectrum (Lie, 2004; Reynolds, 2004; see also the "next generation" program of the U.S. Defense Advanced Research Projects Agency).

There is another reason why "spectrum commons" favored innovation, and this is linked in some way to the "end-to-end principle" (Saltzer et al., 1981). This principle, when applied to network design, states that the network should be as simple and neutral as possible, leaving the "intelligence" at the ends, that is to the applications. The reason why this principle fosters innovation is that it allows flexibility for future uses: a very complex architecture might be optimized for one or more uses, but most probably it will not be good for all the future uses yet unseen. In much the same way, radio devices emitting in the spectrum commons have to respect very general rules, mainly aimed at reducing mutual interference and allowing the peaceful coexistence of different systems in the same frequency bands (see for example the Part 15 rules of the U.S. Federal Communication Commission, that define conditions under which radio devices can operate license-free). Moreover, because emission in the spectrum commons is free, developers are pushed to design advanced techniques in order to protect their system from unwanted interference of any kind (e.g., other radio systems, microwave ovens, etc.) and to share the available spectrum in the best way. Traditional wireless systems assume the receiving terminal is "dumb," in the sense that it cannot easily differentiate between the information signal and background noise. In traditional systems, interference should be avoided at all costs, and this is usually achieved by imposing exclusive licenses and strict regulations about how the spectrum must be used, by whom and for what use. The intelligence is placed in the way the spectrum is managed by regulatory administrations, not at the ends in smart terminals. Recent smart radio terminals developed for use in the license-exempt bands, on the other hand, embed advanced signal processing techniques to sift through interference and pick out the information signal.

REFERENCE MODELS

The vision of the wireless world proposed by the Wireless World Research Forum (The Book of Visions, 2001) puts users and their needs at the core of the definition of network architecture. This user-centric approach can be described by a "multi-sphere model," where the user and the external resources interact via communication links on different levels that can be depicted as concentric spheres around the user. The inner sphere represents the closest interaction with small devices in the personal area of the user. This involves Body Area Networks (BAN), connecting wearable appliances, body sensors and portable devices, such as cellular phones and audio headsets. The next level of interaction is with objects around us, such as personal computers, TV sets and other home appliances that form our Personal Area Network (PAN). The next concentric sphere outwards represents interaction with resources confined in a limited area, usually building-wide, connected together to form a Local Area Network (LAN). Over wider areas, we can interact with any resource in the world through Metropolitan Area Networks (MAN) at city level and Wide Area Networks (WAN) at regional, national and international level, represented by the outermost sphere. Because of regulatory limitations of the allowed transmission power, the advanced wireless technologies developed for use in license-exempt bands can operate only in the inner spheres, up to LAN level included.

This reference model, however, developed around a human user, is not well suited for yet another increasingly important scenario of innovation: Machine-to-Machine (M2M) networking. In this case, the vision is of a world of interconnected devices with distributed "intelligence" that can talk to each other through a mesh of communication links. Some of these devices can be extremely simple and small, such as tiny sensors or smart tags that can be spread over a wide area for monitoring or control purposes ("sensor dust"). In this case, the best reference model is arguably a peer-to-peer architecture supported by a "mesh network," where there's no central or focal point such as in the multi-sphere model, but every node of the network is functionally identical to every other node.

MULTIPLICITY AND CONVERGENCE

Within the inner spheres of the multi-sphere model, a multiplicity of heterogeneous wireless technologies have been designed and deployed, to better fulfill specific user needs at different mobility levels, bit-rates, costs and services provided. Each radio technology is best suited to specific scenarios and applications, hence multiple wireless technologies are foreseen to co-exist in the short-term at different levels of interaction with the user (Redaelli, De Francesco & Ragazzi, 2003).

The transmission techniques developed for license-exempt use must comply with local regulations and must be designed to cope with harsh propagation environments and all sorts of unwanted interferers. The most important transmission techniques for this kind of applications are: *spread spectrum*, frequently used in today's wireless products due to its robustness against noise and interference; *orthogonal frequency division multiplexing* (OFDM), implemented in more recent wireless LAN products and considered also for use in Metropolitan Area Networks; *ultra wide band* (UWB), currently under investigation.

Spread spectrum is a technique pioneered by the army trading bandwidth for robustness. It uses more bandwidth than required to reduce the impact of localized interferences. Usually, one of two main spread spectrum technique is used: *direct sequence* and *frequency hopping*.

The principle of direct sequence spread spectrum is to spread the signal energy on a larger band by multiplying it with a *code*, a fast repetitive pattern of bits. In this way, for each bit of information the system actually transmits many bits of code organized in a pre-defined pattern known both at the transmitter and the receiver. The energy of the signal is spread over so a large bandwidth that it looks just like background noise to "traditional" radio receivers, which may not be significantly interfered with by spread spectrum transmissions. At the intended receiver, the original signal is recovered by correlating the wideband signal with the same spreading code used by the transmitter. Only the original signal gives the best match at the correlator block and therefore the impact of