A Quest for the Future of Wireless Communications or It's Tough to be a Seer

by Zygmunt J. Haas

I admit – I never suspected that writing this article will turn into such an adventure. When I accepted the invitation, I thought that I will be done in 3-4 hours, especially since my research was always leaning towards forward-looking work. And I definitely did not anticipate the need to beg Sam for one extension after another. But most of all, I did not imagine that the search for the future will take me to the dumpsters of Rhodes Hall. … But let's start from the beginning.

I cleaned my desk and equipped with a blank pad of paper and a sharpened pencil, I sat down to write. However, after sitting for over an hour trying to imagine how the wireless world will turn out in 10 or so years, I realized three things. First, that the occupation of a *seer* is not an easy one. Second, that I definitely should not quit my academic position for a career of a writer. But, above all, that I either come up with a different and effective way to get some ideas about this article, or I am in big trouble.

So, being an engineer in soul (after all, I did spend over 9 years of my life working for industry), I decided to take a more pragmatic approach. What would I consider to be sufficiently imaginative and innovative ideas as a prediction for the future? And mind you, no wireless brain transplants, no communications among intra-planetary colonies, and none of these cute extraterrestrial creatures running around with antennas on their heads. After all, I was supposed to be a *seer* and not a *wizard.* I wanted my prediction about the wireless communications future to be feasible and at least reasonably probably, but also tough to attain with today's state-of-the-art technologies. I came up with three characteristics on my notepad:

1. it has to be something that is challenging, no "2-dB" improvements; you do not need to be a *seer* to come up with those, just open *any* technical journal or conference proceedings; today's world is full of "2-dB *seers*" and I did not intend to ruin my *seer*'s reputation
2. it has to be feasible to achieve and probable to happen within, say, the next 10 years or so, since I wanted to become a famous *seer* well before I retire (Clif, do not worry – I do not intend to retire before I am 75 years old, unless, of course, I am offered the *Master Seer* position, or I become a famous writer; none of which is highly likely in the near future, as clearly demonstrated by this article)
3. it has to be technology-driven; that is, it is impossible to realize with today's state-of-the-art technologies, but it can become feasible after significant technological advances are made.

Hmmm, so where I was going to find "it"?

"I know, *the folder!*" I exclaimed. "*The folder* must have the answer!" Now, what I need to tell you is that *the folder* is a 3.5-inch thick binder in which I have collected material since I graduated with my Ph.D. degree in 1988. Each time that I saw something interesting, something that I was impressed with as being challenging and futuristic, I would clip it and add it to *the folder.* I grabbed the folder from the shelf. "This is it!" I told myself. "All I have to do is to go through this material and I will find my *seer's* fame."

Surprised I was, when after an hour or so of paging through fading papers, everything in the folder seems to be either already done, could be easily done at present, or is unnecessary to do because we have already implemented better things. Even the relatively recent articles seemed to contain only "2-dB" advances. I was surprised and disappointed … the folder appeared to be closely related to a collection of "infinitely" many standards issued by various international standardization bodies and associated with technologies such as wireless high-speed data, ubiquitous access, intelligent mobile networks, self-organized networks, sensor networks, wireless LANs, cellular systems, quality of

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service wireless communications, reliable and survivable communications, efficient transmission schemes, etc. Many acronyms of current or already former technologies were there: 2G, CDPD, 2.5G, GSM, GPRS, IS54/136, EDGE, IS95, cdmaOne, 3G, cdma2000, WCDMA, Mobile IP, MANET, 4G, etc. All these standards clearly show how much progress has been made in the recent 10-15 years in the field of *Wireless and Mobile Communications and Networks*. These standards represent an impressive heritage which was made possible by the scientific progress and the engineering genius of our technical community. So is there anything left to be invented? Is it the end of the line or is there a next challenge?

Suddenly, I felt dismayed. I tossed *the folder* on my desk, which came to a sudden stop at the edge of the table, pausing for a moment as asking "do you really want to get rid of me?" and continuing its course downwards to the garbage can below, which was already half full of my never-to-be-published seer's ideas. A few moments later, the cleaning person on her daily round of emptying garbage cans, knocked on my door. The trash was gone and my garbage can was shining again with a new white plastic liner covering its inside.

Sitting by my desk, clueless how to proceed, I glanced at the second shelf on my wall. Neatly organized copies of wireless standards caught my eye. "Yes, these are the standards that *the folder* was all about," I mulled over in appreciation. "But, there are so many of these," a thought crossed my mind. I recalled one of my colleagues saying a long time ago, "The good thing about standards is that there are so many of them to choose from. And the bad thing about the standards is … that there are so many of them to choose from." I recall having a long conversation with him late into the evening, discussing why standards, although being able to guide the industry in developing compatible products and to allow customer-beneficial competition, they also hinder the progress of technology and give unfair advantage to bigger and wealthier businesses. So the impact of standards is like a two-edged sword.

While looking at my shelf, I asked myself, "What if, as in "Alice in Wonderland," everything was reversed? What if, instead of too many standards, there would be one, single wireless communication standard?" This single standard would be like a general *framework* that would be the basis for the design and implementation of idealistically every, and more realistically nearly every, wireless network. Well, for one, it would allow me to save some shelf space and make my office a more habitable place. Not to mention the fact that I could probably reduce the height of the stack of "to be read one day" papers, making my office a safer place too. But would such a concept be feasible, be challenging, and require a technology-driven change? Above all, is it really possible that it would happen? And if so, why would it be probable? Indeed, the "why" is probably the most interesting part – why would the industry support such a *framework* effort, an effort that would appear conflicting with the ability of a particular company to promote a specific technology, which could allow product differentiation and an advertising edge to the company?

As any student who took my "Wireless Networks" class could tell you, multiple standards are essential to cover different communication environments, different networking requirements, different economical goals, different spectral use rules (e.g., in different countries), etc. Well, this is a "correct" answer, in the sense that it may earn you a passing grade in that course. But this is also only part of the truth. The fact is that many standards are created to promote one technology as opposed to another, often when the engineering (and scientific) advantages of one technology have little to do with the technology selection process. Frequently, the choice is made by a company, for example, to support a technology because the company's past products would fare better with proliferation of one particular technology. And here the "Golden Rule" applies quite well … "whoever holds the gold, rules."

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"But wait, there was something about this in *the folder*," I realized suddenly. "Yes, definitely there was something about *technology unification*." My eyes glazed at the empty garbage can. "I have to find the folder!" I rushed to find the cleaning person, but she was already long gone. "Where do they keep the garbage collected from offices?" I briefly recalled that there are dumpsters on the basement level of Rhodes Hall near the loading docks. I did not wait for an elevator, but charged down the stairs to the basement and to the loading docks. (Definitely this qualified as my workout for the day.) "Yes, here they are … the dumpsters are in their usual place," I said to myself, taking a cursory look at their inside. All the dumpsters were empty except for one, which contained transparent-plastic garbage bags, revealing the bags' content. A closer look at some of this content extinguished my enthusiasm quite rapidly. "No, no! No respectable *seer* will go that far as climbing inside a dumpster and going through the trash to find his/her prophecy." I started wondering whether I should have had recruited an apprentice - you know, like most famous wizards have – before embarking on the mission of writing this piece. But the fact is that I did not have an apprentice and I had to get to the bag that contained *the folder* and the sooner the better, as I had only a very vague idea about the time-decay constants of the materials inside some of those plastic bags.

What I realized that afternoon is that human ingenuity has no boundaries. Noticing another empty dumpster nearby, I drove it down below the loading dock. Then, I moved and tilted the full dumpster onto the loading dock, just below the empty dumpster. I put a large wooden platform on top of the empty dumpster. Titling the full dumpster more and more each time discharged some of the garbage bags on the wooden platform. Quick examination was needed to determine whether the current batch contained the remains of *the folder*. If not, the batched was "released" to the empty dumpster and a new batch was delivered by an additional tilt of the upper dumpster.

It took three batches to discover the garbage bag. Excited, I pulled page by page (for those who wonder - yes, I put on rubber gloves, which I borrowed from a janitor who did not even try to hide his amusement). Not too long thereafter I found what I was looking for – a vu-graph, no, not simply a vu-graph. It was MY vu-graph that I made for myself just before my Ph.D. graduation, 17 years go! The vu-graph presented the concept of a *Unified Wireless Framework*, one that can adaptively support communication in any propagation medium, with a single medium access control, for any user application requirements and characteristics, etc, etc, etc. Of course, 17 years ago, I had absolutely no idea how this should be implemented. And, honestly, I have no idea now how to do this either. But it's a 1) *challenging* concept, 2) one that should be technically *feasible* to realize in the next 10 or so year, and 3) one that requires *technological advances* to implement. So, it's a *seer*, even though it's only a beginning of a *seer*.

But what exactly is this *seer*? The concept advocates that the dependencies of wireless communications on specifics of the communication environment should be hidden by dynamically adjustable implementation of protocols, where "dynamically" means "automatically and during the operation of the protocol," and "adjustable" refers to the "adaptively reconfigurable" characteristic of the protocols. Thus, the concept allows defining a single standard for each of the communication protocol layers, independent of the actual parameters of the communication environment. For instance, although communication through a wireless medium depends on the carrier frequency, transmission through media nearly always involves excitation of waves within the media. (And most often, the waves are in the electro-magnetic fields, but there are exceptions, such as acoustic or underwater communication.) Yes, if the excitation is at high frequencies, it will produce light, while at lower frequencies, it is radio waves. While the basic concept of generation of propagating energy remains the same, the differences are in the implementation itself (i.e., frequency of excitation, in this case). Now take a look at the modulation schemes. There are many different types of modulations; for instance, in the digital modulation domain, some examples include: ASK, PSK, FSK, and QPSK. Yes, but the basic notion of modulation is the same, with the different schemes differing in the details of

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how and what is modulated. I could go on, telling you that pulse encoding schemes, framing schemes, MAC protocols, the network protocols, etc, can each be represented by a single general canonical scheme, where the variants are created by setting the input parameters of this canonical scheme. Thus, all of the elements of the communication process are present in the *Unified Wireless Framework,* but each one consists of a canonical, generic scheme, one that can be easily "morphed" into performing any desired variance of the functionality of the scheme. It is as the schemes are boxes with a number of dials, each dial can be dynamically adapted, so that a box change the way it performs a specific function. All the protocols developed for a specific function are selectable by the box's dials, but the selection is continuous, allowing selection (and even mixing) of values within the "gaps" between the values "rigidly" defined by the variants of these protocols.

Well, this was the *Unified Wireless Framework,* a concept that I dreamed about 17 years ago. Given the current abundance of protocols for wireless communication, the concept is still to a large degree a dream, but not totally a dream. Take a as an example, *Software Radio;* it's the framework's concept at its infancy.

So my *seer* to you, my friends, is that in 10-15 years we will see a clear convergence of standards, both in terms of their functionalities and in terms of how they address the overall system design. We will see standards being merged together as technologies evolve, allowing construction of significantly more capable systems with larger data rate and larger processing rates. We will see systems being more dynamically (i.e., autonomously) adaptive; i.e., systems that can sense the environment and its limitations and adapt the operation of the protocols in a continuous way, rather than switching from one scheme to another. And, finally, systems based on comprehensive cross-layer design (rather than two-adjacent-layer cross-layer design), automatically updating and adjusting the settings across, what we consider, the traditional layered design.

But wait, I swept something under the rug here. In my reasoning of why the *Unified Wireless Framework* is a *seer*, I "forgot" to explain why the concept is not only feasible, but is also probably. Yes, I do believe that the industry itself will be the driving force behind this convergence of technologies and, consequently, their standards. Although there are several rationales for this prediction, let's just examine one – the increased technical difficulties in implementation of very large and complex systems. We are on the path to realization of the "pervasive and ubiquitous" vision, where everything can communicate with everything else. With no unification in the design of the various systems, conversion and translation between the various protocols will become a nightmare. And with no autonomous adaptivity in the selection of the protocols used, the interaction and the interference at the various layers of the communications process will result in a total chaos. Essentially, most of the communication resources will be wasted on the control of the communicating systems, concentrating on avoiding interference and oscillations, with little resources left to support the actual communication goals. Unification and dynamic adaptivity across a continuous range of protocols implementation will be the only way to cope with such a complex world of future wireless communication, ensuring efficiency and stability.

And that's all the *seer*, folks. Was it worth the adventure and the embarrassment? Only the future can reveal the answer. But I did learn a lesson … *try first our own dreams, before exploring others'.*

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