Very Large System Design: Introduction and Report

From October 2010 *High Frequency Electronics*
Copyright © 2010 Summit Technical Media, LLC

Very large systems present a unique set of problems in design and operation. The earliest such systems, such as the telephone network and the power grid, created the need to develop operational techniques that maintained reliable operation. The development of those systems created the first theoretical and analytical models of networks, which—over 100+ years' time—have led to new ideas in the management of large systems, including distributed networks, complex hardware, and even large groups of people.

When this report topic was scheduled in mid-2009, the extent of the subject was not fully appreciated—the focus was on issues that were rapidly growing in importance in wireless networks. Because the study of large system concepts extends well beyond wireless networks, we have chosen to present this report mainly as an introduction to key concepts. We will explore additional wireless applications in future technical articles.

Large, Complex Systems

Some current large systems are well-known, while others may be unfamiliar to the general public. Some of today's large systems include:

The Internet
Military C3I (command, control, communications)
Wireless service provider networks
Research/corporate computer networks
Smart factory systems
CPUs, DSP and other computing ICs
Computer software

Perhaps the most challenging problem facing the high frequency industry is the need to support *convergence* (4G and beyond) in the near future. The desire for "wireless anywhere/work anywhere" requires increased complexity of user devices, infrastructure hardware and operational management software. Coordination of large groups of design and operations personnel adds a human element to the problem.

Existing Methods

Before returning to wireless network issues, it is worthwhile to review some of the current methods of managing large systems. Here are a few typical techniques with brief comments:

Scaling/Replicating—Some systems' growth may be managed by simply adding sub-systems that use current architecture and control methods. Adding more hardware, power, personnel, computing power and other supporting resources may be sufficient. This is a common method, since it does not require radical changes until growth reaches a level where a complete reconfiguration makes sense. For example, this appears to be the current status of the power grid, which has grown using established methods, but which can no longer expand without implementing new "smart grid" methods that are now in development.

Hierarchical structures—Often associated with the previous method of system expansion, top-down management is required for certain large systems. Governments, the military and corporations work this way.

Current wireless service provider networks also operate in a hierarchical manner. At the bottom are individual users, connected to cell sites, which are routed by backbone communications to central switching hubs, all coordinated by a central traffic management system. In part, this structure has been needed to capture call information for usage reporting and customer billing.

Distributed structure—There are a collection of terms describing distributed systems. Wireless communications may have *ad hoc*, *peer-to-peer*, *mesh*, *self-organizing*, or *adaptive* networks. Briefly, these networks are created using available resources—individual users' devices, cell sites, WiFi hot spots, wired connections, etc. These network nodes change as users move, turn on and off their devices, etc. Data traffic through the network is also variable, ranging from a few users using voice or text, to multiple users streaming video. These networks are designed to organize data routing in the most reliable manner, adapting to the changes in nodes and usage.

First used in WiFi networks, these systems are also the standard method for sensor networks, used for building lighting and HVAC control, process flow in factories and test platforms for critical systems such as aircraft. Large sensor networks also include automated weather data reporting, stream and river level monitoring, and vehicular traffic flow monitoring.

Wireless providers are planning to use elements of these techniques to optimize base station coverage and network configurations for broadband services. Motorola, NEC and Nokia Siemens are all promoting "Self Organizing Network" technology for more efficient operation of LTE networks [1, 2, 3]. According to a report from Nokia Siemens Networks [3], the factors driving self-organizing networks include:

- Saturated markets, revenue per bit is dropping
- Parallel operation of LTE with 2G and 3G networks
- Large and complex number and structure of network parameters
- Expanding number of Base Stations

These automated data flow management systems are intended to replace central office control of remote sites. At present, a significant portion of base station setup and operating control is still performed manually. Simulation and testing suggest that these automated systems will be a reliable and effective means of optimizing network operations.

Another use of self-organizing network technology is in the extension of wireless networks. Micro-, pico- and femto-cells are seen as a viable method of extending the reach and capacity of a network into areas with either difficult propagation or highly variable—sometimes very heavy—user loading. Automated operational management of these network extensions is a necessity for them to be responsive to changing conditions. There is research underway at present to examine the effects of these semi-autonomous network extensions, since they do not support direct monitoring by the central operations staff.

Large System Design Process

The computer industry has dealt with large systems for many years, in both hardware and software. Current CPUs, DSP, and other devices have complexity levels that are a challenge to manage and coordinate at the design stages, and it is nearly impossible to test 100% of their functionality. Software is also extremely complex, with millions of lines of code requiring the efforts of hundreds of programmers and needing many MBytes of memory to operate.

A key issue is managing engineering design in ever-larger collaborative groups. This is where the computer industry has done significant research. One classic report [4] identified the four areas of management of a very large project:

- Management of the Product—Version control, system design and construction control, and traceability of all system components.
- Management of the Process—Standards and protocols, reporting and documentation procedures, task assignments and personnel management.
- Management of Resources—Costs, facilities and staff support, employment (number of staff available), and monitoring of ongoing resource usage.
- Management of the Environment—Available software tools (including upgrades during development), prototyping and instrumentation capabilities, monitoring progress and adapting or improving management methods.

Computing hardware or software is usually well-defined in terms of functionality, and the goal is to have a finished product that delivers these functions in an orderly and consistent manner. Although complicated, the process can be described by flow charts showing the necessary sequences of operations and feedback paths for corrective action.

Large wireless networks present a different set of problems. Although the organizational structures developed for computer system design are highly valuable in the design of these applications, the end product is significantly different. In computer systems, most functionality is static—well-defined inputs and outputs. But in a wireless network, the mobility of users means that it is primarily dynamic, with constantly changing operating parameters and configurations. Thus, the lessons from the computer industry must be adapted for largely different system goals.

Research Activities

Among the areas of research noted by the many universities studying this topic are:

Modeling—Mathematical representation of complex interactions, with widely varying structures that may be sufficiently complex to be considered random.

Analysis—Development of algorithms to search extremely large data sets and extract specific information. This is the Internet search engine scenario, but there are many other possible applications from health study to delivery of custom services.

Adaptive Networks—The study of systems that respond to a changing environment, such as ad hoc, self-organizing, self-healing, adaptive bandwidth networks, and many more possibilities. There is also study on combinations of network types, such as a hierarchically organized backbone with self-organized extensions.

Security

Finally, in very large networks security is a major issue, since there are so many interconnections and available points of access. Digital security uses codes based on random numbers, so it is no surprise that random number generation is a key research topic. Research in this area has two directions. The first is high-level, with efforts to develop "perfect" random number generators based on quantum physics. The other is at the low end, attempting to find the best possible noise-based random number generators with small size and minimal power consumption [5].

References

1. "LTE Operations and Maintenance Strategy: Using Self-Organizing Networks to Reduce OPEX," Motorola Inc., March 2009.
2. "Self Organizing Network," NEC Corp., February 2009.
3. Werner Mohr, Nokia Siemens Networks, "Self Organizing Networks: A Manufacturers View," ICT Mobile Summit, Santander, Spain, June 2009.
4. Peter Feiler and Roger Smeaton, "Managing Development of Very Large Systems: Implications for Integrated Environment Architectures," Carnegie Mellon Univ. Technical Report, May 1988.
5. "Lightweight True Random Number Generators a Step Closer," Press Release, Queen's University Belfast, September 2010.