Opportunities and Challenges in Realizing a Global (Mobile) Military Information Infrastructure

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The vision of a global network-centric tactical military infrastructure is compelling in that it is based on a construct that moves information rapidly from any source to any sink across the military on an as-needed basis: "the right information to the right place at the right time" as it is so often quoted. The realization of the tremendous opportunity offered by such an infrastructure hinges on the resolution of a number of significant engineering challenges; challenges that are manifested by the fact that military networks have characteristics that transcend the current state-of-the-art in networking today, namely that they are built on communication links that are inherently *unpredictable*. This talk presents a framework for addressing some of these challenges in fundamental ways that recognizes this underlying unpredictability of the physical layer and relates it to the achievable Quality of Service (QoS) and the associated complexity of the systems required to manage it. While such a framework ultimately helps researchers, engineers, and program managers make wise technology investment decisions, it is important to build a "technology roadmap" that is ultimately tied to operational capabilities.

Despite many years of financially intensive investments toward the realization of large-scale tactical military networks, relatively little progress has been made especially when compared to those of the commercial networking domain. While the vision of "network centricity" draws heavily and naturally on the apparent ease and ubiquity of the Internet, building a "military Internet" is proving to be much more difficult than the build-out of mobility in the commercial Internet. This is primarily due to the fact that while commercial telecommunication networks are predominantly built on top of wired, relatively stable connections, tactical military networks must cope with fundamentally different underlying operating characteristics, hostile environments, and dynamic link conditions. This, in turn, is due partly to the demanding blend of two historically different engineering disciplines: radio communication engineering and network engineering. While communication engineering has information theory as its foundation, there is no fundamental theory of networks.

If we are to realize large-scale, robust mobile tactical military infrastructure that can truly withstand the rigours of both war and peace, we are faced with the Grand Challenge of the development of a Fundamental Theory of Networks. We simply cannot design, build, and mange networks according to twenty year old methodologies such as strict layered architectures which were developed for highly *predictable* fixed infrastructures. The major challenges in next-generation military communication networks will be a direct consequence of dynamic, *unpredictable* operating conditions.

The guiding objective of architecting tactical military wireless networks must be the *management* of Quality of Service (QoS). QoS, however, must be defined in a much broader sense than traditionally used

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by network engineers. We define the Quality of Service as "*the degree to which the right information is able to be delivered to the right place at the right time*". By defining QoS in this sense, the business of network planning, management, optimization, and operations can collectively be viewed as QoS management. Such a holistic view is necessary to construct a lasting foundation for such disparate, large-scale networks. This is in direct contrast to the strictly-layered approach currently being pursued in military network design simply because it has historically worked so well in the design of commercial infrastructure. The management of QoS must be approached *across* the protocol stack in a deterministic design method. This cross-layer design (CLD) approach has recently been receiving attention in the cellular and mobile *ad hoc* network research areas although with no fundamental framework or guidance.

Predictability is likewise defined as *the measure of the degree to which the state of the network can be reliably observed*. Naturally, fixed-base terrestrial communications are highly predictable; space-based networks are moderately predictable, while tactical mobile networks are the least predictable. This decrease in predictability is due to several factors the most fundamental of which are topological time variance, dynamically changing traffic flows from node-to-node (heterogeneity), and the underlying channel statistics incorporating varying capacities and fading effects.

It is therefore recognized that as the physical layer becomes less predictable, cross-layer coupling and optimizations that exploit "knowledge" of the underlying communication path among the layers is needed. CLD, however, lacks a rigorous theoretical approach but then so does our current large-scale mobile network engineering science. Given a large mobile mesh or *ad hoc* military network, who can say what the achievable end-to-end communication capacity is? Without such knowledge, the objective utility and even viability of a given system design is undeterminable; we simply don't know how good we're doing. We need a bound against which the degree of design optimization can be benchmarked and assessed. Radio science has evolved through benchmarking relative to the point-to-point channel capacity defined by Shannon's Capacity Theorem. However, such a theoretical approach will be impossible for networking if strict layering is not rejected since cross-layer design optimization will be an important element of any theoretical framework.

With this basis, we are now prepared to sketch out a predictability-based framework by recognizing that within a predictability class (low, moderate, high), for any given system, the complexity of a QoS management solution translates to an *achievable* QoS. That is, after a certain level of "QoS complexity" is built into a system design, there are diminishing returns for increasing that level of complexity. This simple recognition can be used to guide investment, network planning, management, and control activities to ensure a more efficient design while not squandering resources.

The visions of Network Enabled Capabilities (NEC) and Network-Centric Warfare (NCW) have become widely accepted yet large-scale realization of next-generation military networks seems increasingly elusive. Without communications, the military "mission" cannot be accomplished; before us stands a tremendous opportunity to change the face of military communications through patience, discipline, and the true application of science.