IMPROVED ANALYTICAL TOOLS FOR PREDICTING WIRELESS NETWORK PERFORMANCE

M. D. Ginsberg
US Army Engineer Research & Development Center
Champaign, Illinois, 61801

Abstract

Recent research has derived analytical tools that should correctly predict the effects of queuing delay and consumption of spatial resources. Although these tools improve on available prediction capabilities, they still do not correctly predict the scaling laws observed in real wireless networks. Real networks do not perform as well as the theory predicts they should. This paper cites current research directed toward understanding the discrepancy between theoretical and empirical results. Surprisingly, both theoretical and empirical results show that the throughput capacity of wireless networks is likely to pose specific limitations on the agility and deployability of the Objective Force. These limitations may be eased somewhat through decentralization of logistical and command and control decisions.

1. Background

Army demand for wireless data networks is increasing rapidly. An example of Army demand includes almost every aspect of the Future Combat System, in which "… communication networks…are the core of every aspect of military activity,"[Latham 2000]. New networks for unmanned vehicles, sensor packages, indirect fire control, optimized logistics, split base operations, and other applications are needed to fulfill the Army's concept for the Objective Force.

One might believe that DOD would have no meaningful role in the R&D of these systems. Given civilian demand for apparently similar services, new technologies for wireless networks become available for off-the-shelf consumption nearly every month. One must remember two important factors that are not so obvious.

First, the military has unique requirements that are not well met by commercial devices. Where commercial devices assume the existence of various types of infrastructure, such as phone lines, cell phone towers, internet access, etc., the military is commonly asked to operate in environments containing no communication infrastructure at all. This can happen after a natural disaster that has caused widespread devastation like a flood, hurricane, earthquake, etc., or after a military conflict in which crippling the opponent's communications infrastructure is seen as a decisive advantage. Realizing that the military must pursue mission objectives under these extreme conditions, DOD has actively sponsored development of communication network protocols where each node must double as a network router, dubbed "ad-hoc networks." The standards for these networks are still under development in the academic community.

Second, the theoretical understanding of network capacity is surprisingly weak. Despite recent improvements, there are no accurate theoretical models that can predict wireless network system performance, even when the software architecture along with all embedded parameters are known. Theoreticians are still debating how to improve wireless network characterization while prospective vendors have no accepted way of summarizing suitability to purpose. In other words, there is no way to predict if the network design under consideration will fulfill specific mission requirements. This research, in direct cooperation with existing programs at ARO and AFOSR, is intended to improve existing models of network performance.

2.1 Theoretical Results

Recent results show that as more nodes participate in a network, the bandwidth available to each node grows smaller. This fact is not surprising. Consider a room containing N people, each of whom talks quite loudly so that only one can talk at a time. Even when all present agree to take turns, the amount of time any one individual can talk goes down as 1/N. One might expect that if everyone in the crowd of N talks softly enough, that more conversations can take place and that this figure might be improved. Indeed, it is predicted in this case that one should be able to talk proportional to (1/sqrt(N ln N)) of the time [Gupta 2000]. Although better, this is an alarming degradation in performance. At 38 nodes, each node can only access <5% of the bandwidth available on the network. This is like buying a 56-kilobit per second modem and only being able to obtain 2800 bits per second of throughput. As dismal as this prediction is, empirical results from real data networks are far worse.

2.2 Experimental Results

Experimental studies show that actual throughput goes down as (1/(N^1.78)) obtaining <0.2% of the modem's capacity at 38 nodes. These results are obtained both in field experiments and in simulation, [Ginsberg 1999].

The fidelity of the results obtained in simulation is improving constantly. Further, field trials are conducted at increasingly larger scales each month. The most up-to-date information available will be presented at the poster session.

3. Discussion

It is not understood whether the scaling laws predicted by recent theory are simply wrong because they are incomplete in some way, or if the wireless networks contain design flaws that prevent them from performing adequately. The theory may be inadequate because it cannot account for effects due to: node mobility, channel setup time, channel teardown time, and other system parameters. On the empirical side, wireless data networks consist of multiple software layers, any one of which may either be misdesigned or contain variable parameters that should be tuned more carefully.

Clearly, with results showing that the command and control structure will be severely limited by network throughput, alternate methods of command and control become a necessity.

Recent advances in queuing theory have been spurred by new applications. The most important of these have been: analysis of message traffic loads in the Internet, and batch processing in semiconductor fabrication plants (SFP). Both of these applications lead to networks that are reentrant. SFP analysis has recently yielded interesting results that appear to be applicable to logistical and command-control networks. In an SFP, jobs must flow past several specific machines several times, thus inducing reentrancy. These selected machines may have several batches of wafers waiting for processing. The plant's throughput, therefore, depends critically on deciding which batch should be processed next. Recent results have shown that optimized batch scheduling can be achieved in a decentralized way. The operator of each machine in the plant can decide which batch should be processed next without sharing information with other machine operators [Perkins 1995]. Research on applying these methods to logistical, and a command-control network continues. Successful adaptation would minimize the communication load that command-control functions place on a wireless network.

4. Conclusion

These results suggest that wireless network capacity will represent a fundamental limitation on the agility and deployability of the objective force. Results recently obtained from queuing analysis show that command and control strategies can be streamlined in a way that minimizes network utilization while maximizing force responsiveness.

5. References

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