The Need For Robust Statistical Analysis of MANET Performance Data

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June 24, 2010

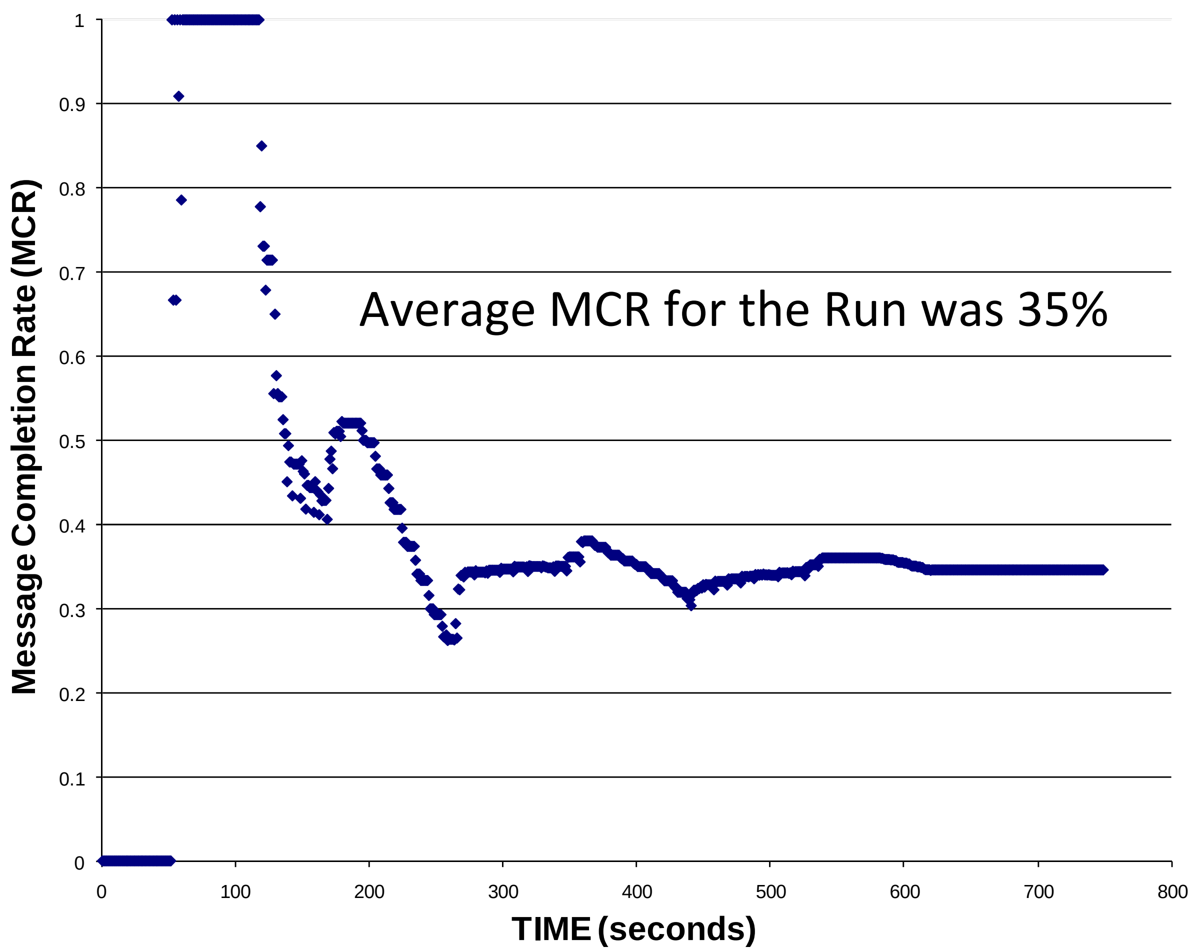
15th International Command and Control Research and Technology Symposium

Future Networks are Being Tested Today

- Our understanding of network performance depends on the quality of analysis
- The analysis can mean the difference between a functioning network and unrealistic expectations

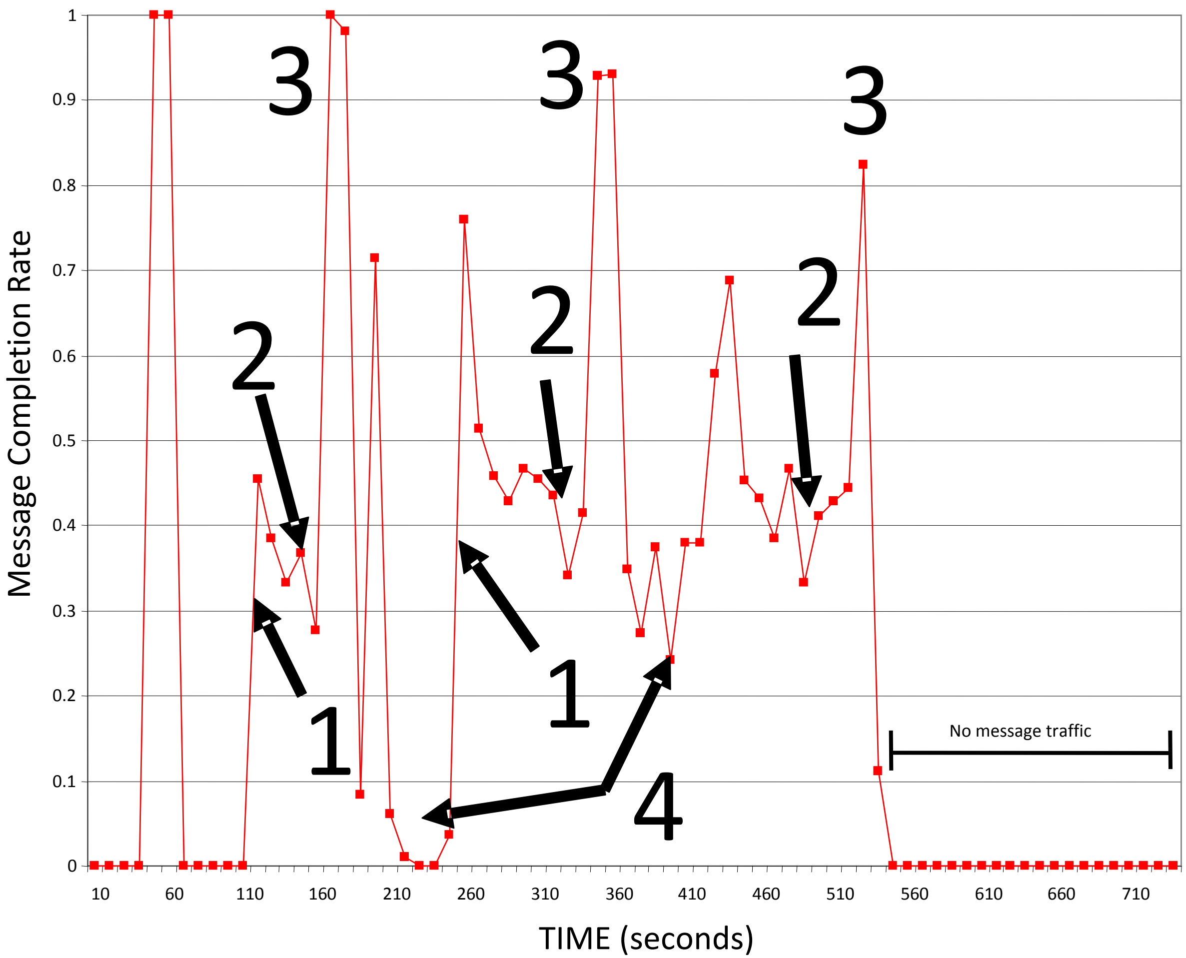
- Common metrics like Message Completion Rate (MCR) and Latency are useful, but potentially misleading because they conflate underlying variables
- We will offer several techniques to help drill down into network performance

Mean Data Can Be Misleading



Taken from "Integrating High Resolution Network Simulation with Force on Force Combat Models: Connecting MANA and QualNet", 10th ICCRTS, June 2005.

Network Throughput is Highly Dynamic



1 = UAV Moves Into Range

2 = Limited Performance Area

3 = Peak Performance Area

4 = Out of Range

Taken from "Integrating High Resolution Network Simulation with Force on Force Combat Models: Connecting MANA and QualNet", 10th ICCRTS, June 2005.

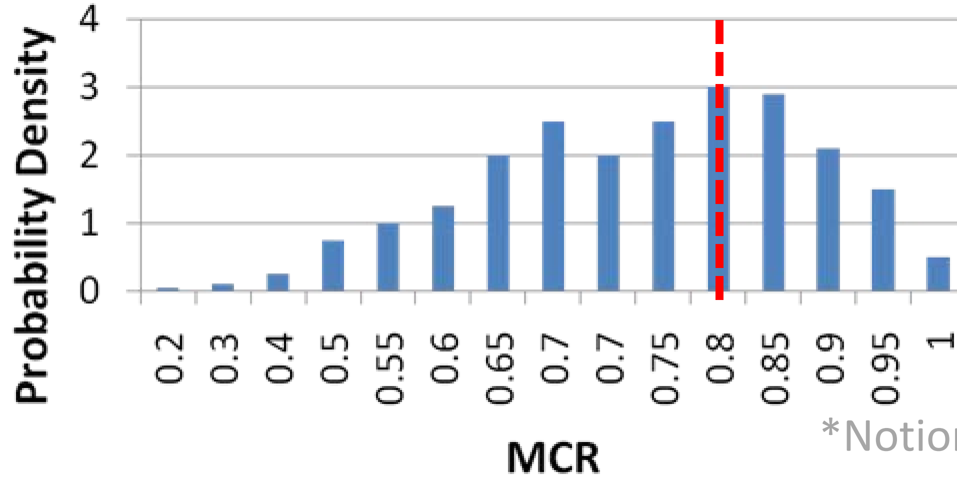
Wireless Network Performance Depends on Many Factors

- Network performance is a complex system, representing the culmination of the interaction of many variables (e.g. below):
  - Physical:
    - Antenna height
    - Line of Sight
    - Frequency and channel size
    - Mobility
    - Environment (e.g. temperature, humidity)
  - Internet / Link
    - Protocol
    - Precedence
    - Topology (hops)
  - Application
    - Offered Load
    - Message Size
  - Other
    - Human operations
    - Crypto
- Many of these factors vary <u>simultaneously</u> during a run

Data Collection is Critical

- The predictive ability of a dataset only goes as far as the data captured
- Statistical models can capture a “catch-all” variable where some results can indicate a large portion of variation that is due to unobserved effects

Distribution shows variability for MCR that averaged .8



*Notional Data

- Tracing the performance of individual packets
- Tracking node pair performance relationships, both end to end and intra-pair
- Routing information

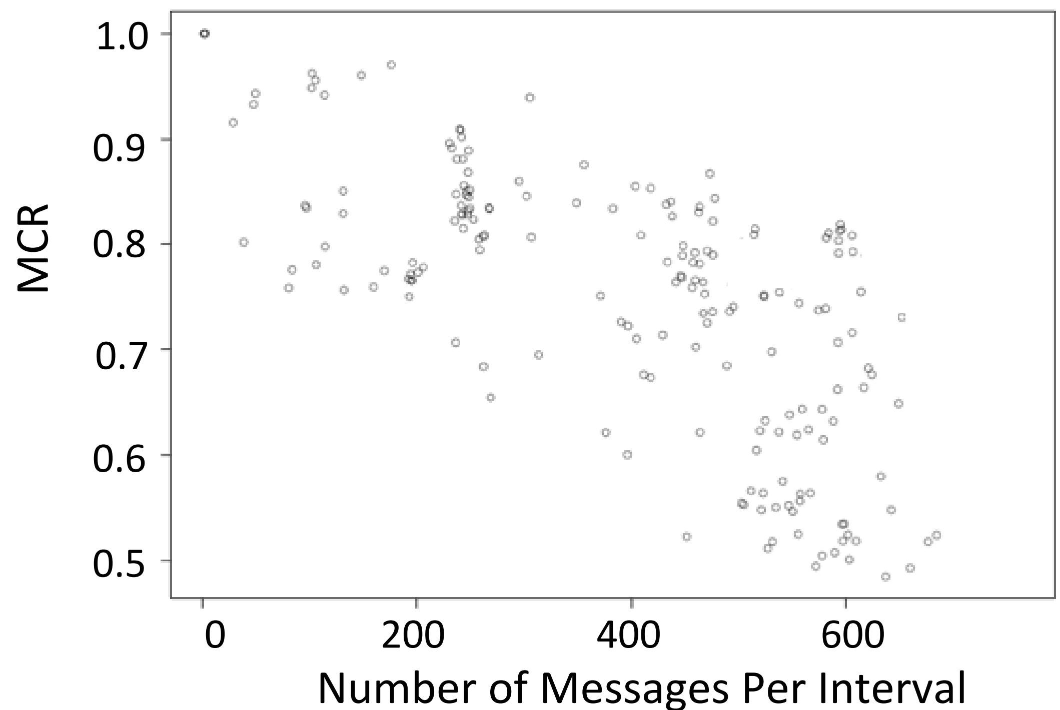
"Any Statement of Relationship Must Be Put Through Sharp Inspection" – Darrell Huff

- If B follows A, then A has caused B
- "I increased my number of network nodes and my MCR improved -> my network is scalable"

- Design of Experiments:
  - Base requirements on received load instead of offered load
  - Small message sizes
- Analysis:
  - Select only "good" runs
  - Use only raw data

A Logical First Step is to Segment the Data

- Averaged MCRs may not vary much across runs, but instantaneous traffic does
- In this case you can create a new variable that bins the traffic into time intervals (e.g. 10 second snapshots)
- Proving that experiment level data is too coarse helps MCR predictions tremendously



*Notional Data

Statistical Analysis Is Used To Determine Factor Significance and Quantify Its Impact

- Regression is designed to parse out effects of multiple variables to isolate its "true" impact
- In our analysis we tend to use two approaches:
  - Inferential Modeling: to quantify the impact of each factor
  - Predictive Modeling: to make the best possible prediction of performance (e.g. MCR, latency, etc.)

Inferential Modeling

- Standard approach for binary outcomes (e.g. MCR), Hierarchical Generalized Linear Models (HGLM)
- Allows investigations of influences of different factors on the probability that a message will be delivered successfully
  - Must account for the multi-level nature of the data with multiple sender/receiver node pairs sharing similar unobserved factors

Sample data showing the impact of factors

Factor	#exp	#pos	#neg	LCL	Estimate	UCL
Protocol – Multicast	10	1	9	-0.49	-0.35	-0.1
Precedence – Priority	10	10	0	0.15	0.21	0.39
Precedence – Immediate	10	10	0	0.45	0.5	0.6
Precedence - Override	10	8	0	0.24	0.46	0.55
Tx Antenna Height 5 m	10	0	0	-0.10	0.16	0.22
Tx Antenna Height 10 m	10	2	4	-0.41	-0.28	-0.14
Rx Antenna Height 5 m	10	1	2	-0.34	-0.19	0.05
Rx Antenna Height 10 m	10	0	7	-0.5	-0.42	-0.34
Tx Mobility 25 mph	10	1	6	-0.54	-0.34	-0.10
Rx Mobility 25 mph	10	1	8	-0.87	-0.61	-0.34
Distance	10	2	6	-0.75	-0.21	0.09
Hops	10	0	8	-0.69	-0.54	-0.29
Offered Load	10	2	8	-0.63	-0.42	-0.21

*Notional Data

Predictive Modeling

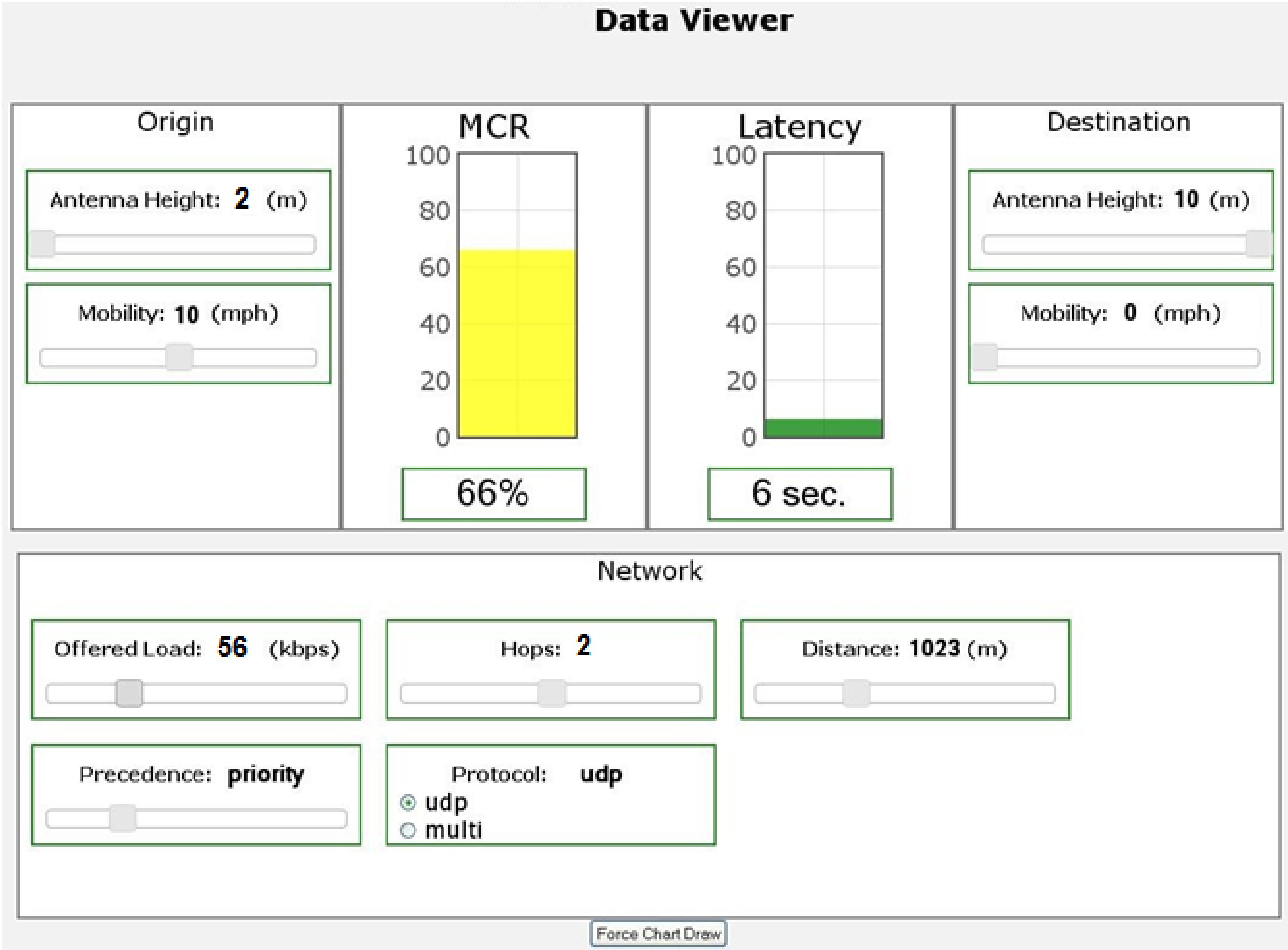
- Creates predictions of performance as a function of input variables
  - Relaxes constraints between variables and performance
  - Allows for multi-way interaction of variables
- Allows for easier comparison between different tests

The Two Techniques Are Complementary

- The inferential model allows us to better understand and interpret the individual factors on performance, holding other factors constant
- The predictive model gives us a better “black box” to predict future performance with parameters similar to those modeled

Visualization of Information is Also Important

- Predictive models are essentially "black boxes" of data that can be hard to interpret



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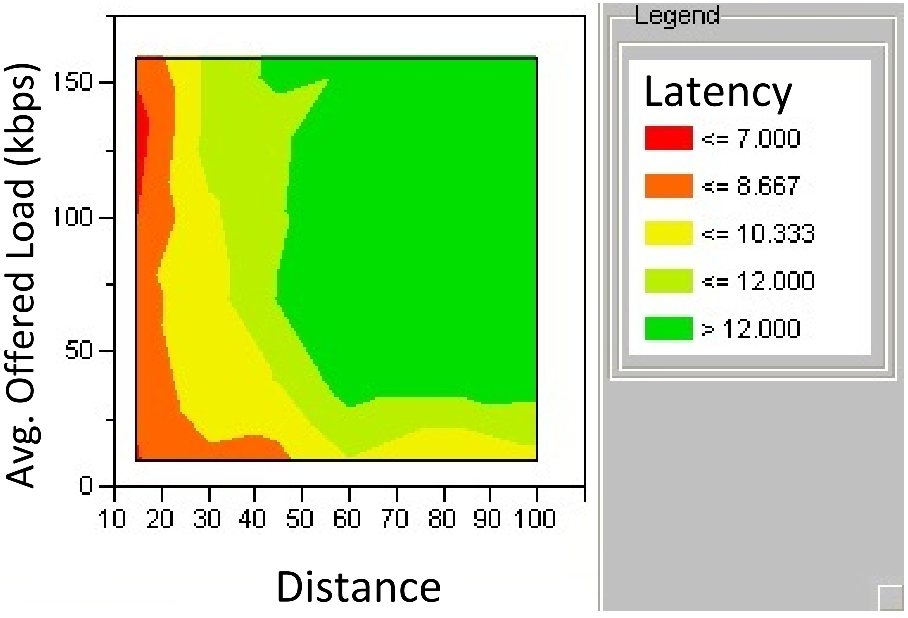
Another Useful Way to Visualize Predictive Data is Through Contour Plots



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Summary

- Analysis of raw and mean data can be misleading
- We're testing our radios now, specifically JTRS WNW
  - With the enormous expense of conducting live experimentation, careful statistical analysis must be done to understand the "true" nature of performance
- Successful experimentation may include:
  - Interesting DoE (i.e. the right variables and ranges of those variables)
  - Robust data collection techniques (that don't interfere with the radios)
  - Statistical analysis to fight bias

Questions

- How will network managers network performance?