RAND ARROYO CENTER

Framework for Measuring the Impact of C4ISR Technologies and Concepts on Warfighter Effectiveness Using High Resolution Simulation

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Motivation: Address "Value of Pound of C4ISR" Question

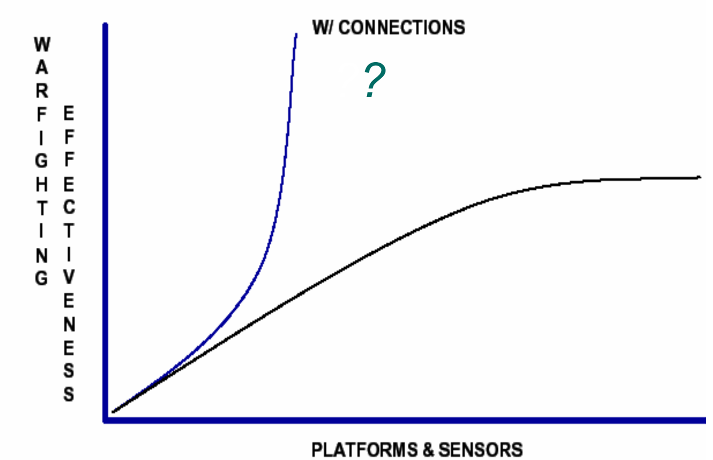
1. **Need to capture marginal impact of technology options**

   How much better is C4ISR performance given:

   - **Additional bandwidth, new technologies (e.g. radios, antennas, etc.)**
   - **More (or less) sensor data**
   - **More (or less) frequent COP update**
   - **Enhanced connectivity**

2. **Need to quantify C4ISR benefits into combat outcomes**

   What are effects on warfighter?



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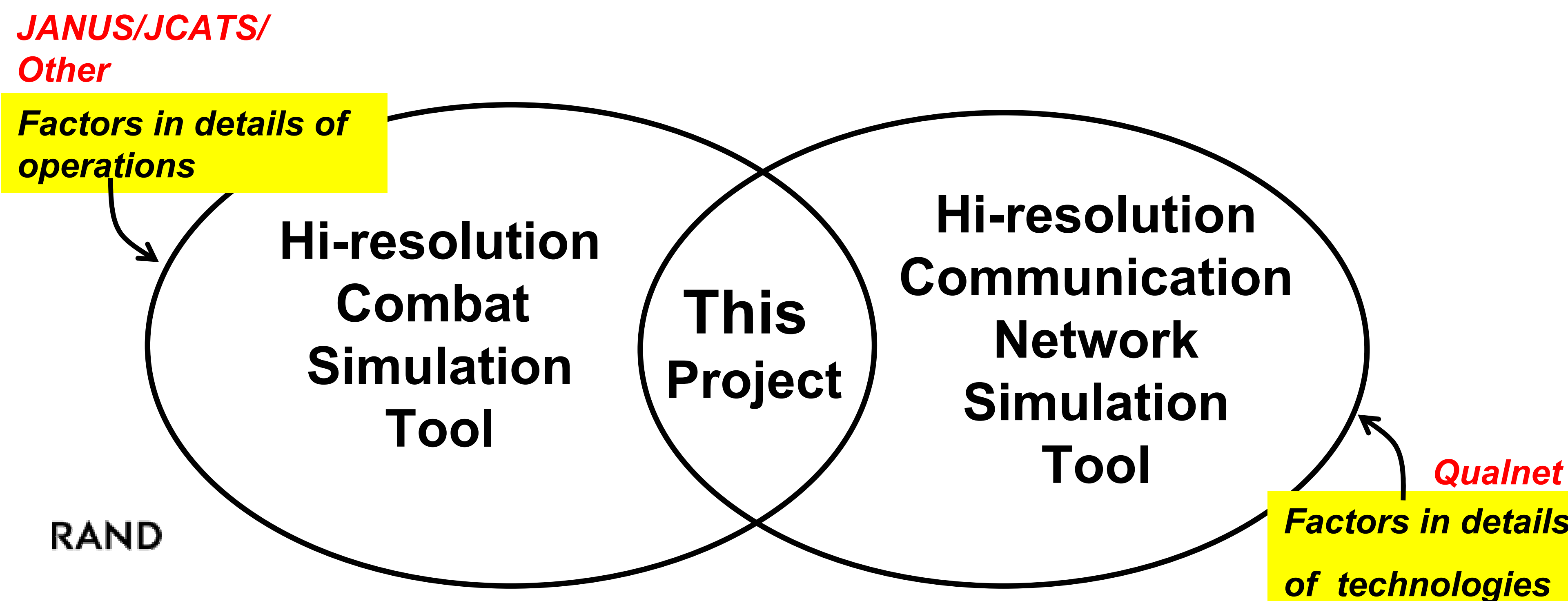
Source: Fisher, 2003

Approach: Capture Technology and Scenario-Specific Detail

- **Network performance highly sensitive to technology detail and scenario specifics**
  - **Technology options and combinations of options are numerous**
  - **Terrain/scenario has a large impact**
  - **Vehicle characteristics (e.g., mobility) affects network performance, reliability, etc.**



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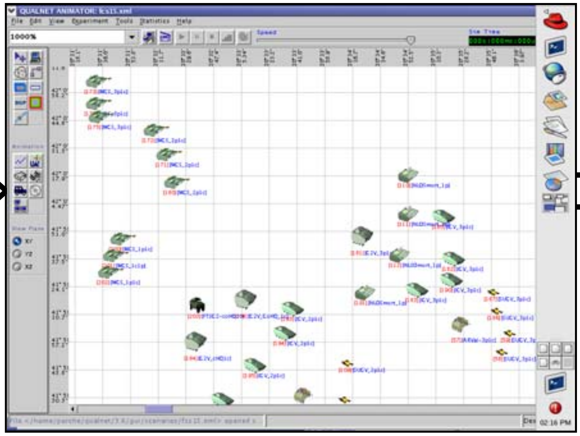
Qualnet Simulations Used To Develop Performance Curves

Parameters (Tech. Options)

- Traffic volume & type
- Terrain type
- Number of Nodes
- Node mobility
- Other factors

Qualnet Simulations

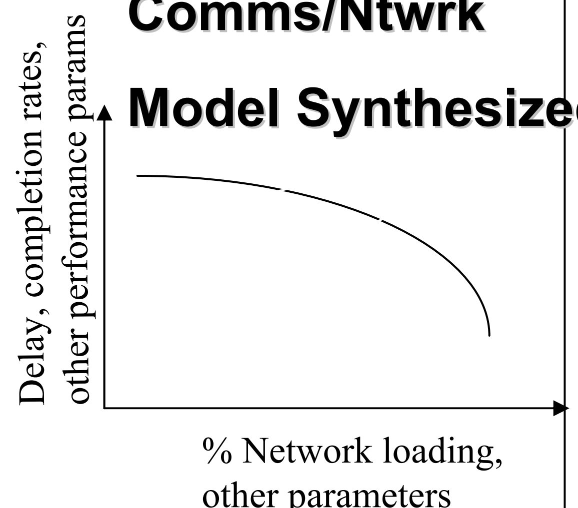


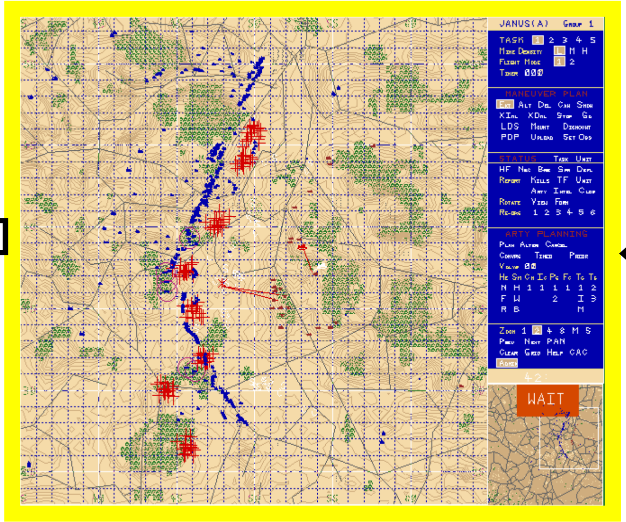
Performance Data

For each parameters (Message type, tech, etc,)

- Completion rates
- Latency

Comms/Ntwrk Model Synthesized





JANUS Simulations

Warfighter Effectiveness

e.g., mission execution, attrition, etc.

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Why a Meta-Model?

1. Communication network simulation is complex and time consuming
2. Meta-models allow flexibility while not adding large overhead time to combat simulations
3. Regression analysis can be used to generate a model “off-line”

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Terrain/Scenario Being Studied

- ***Network performance inside individual boxes is modeled***
- ***Boxes vary in size and terrain roughness***

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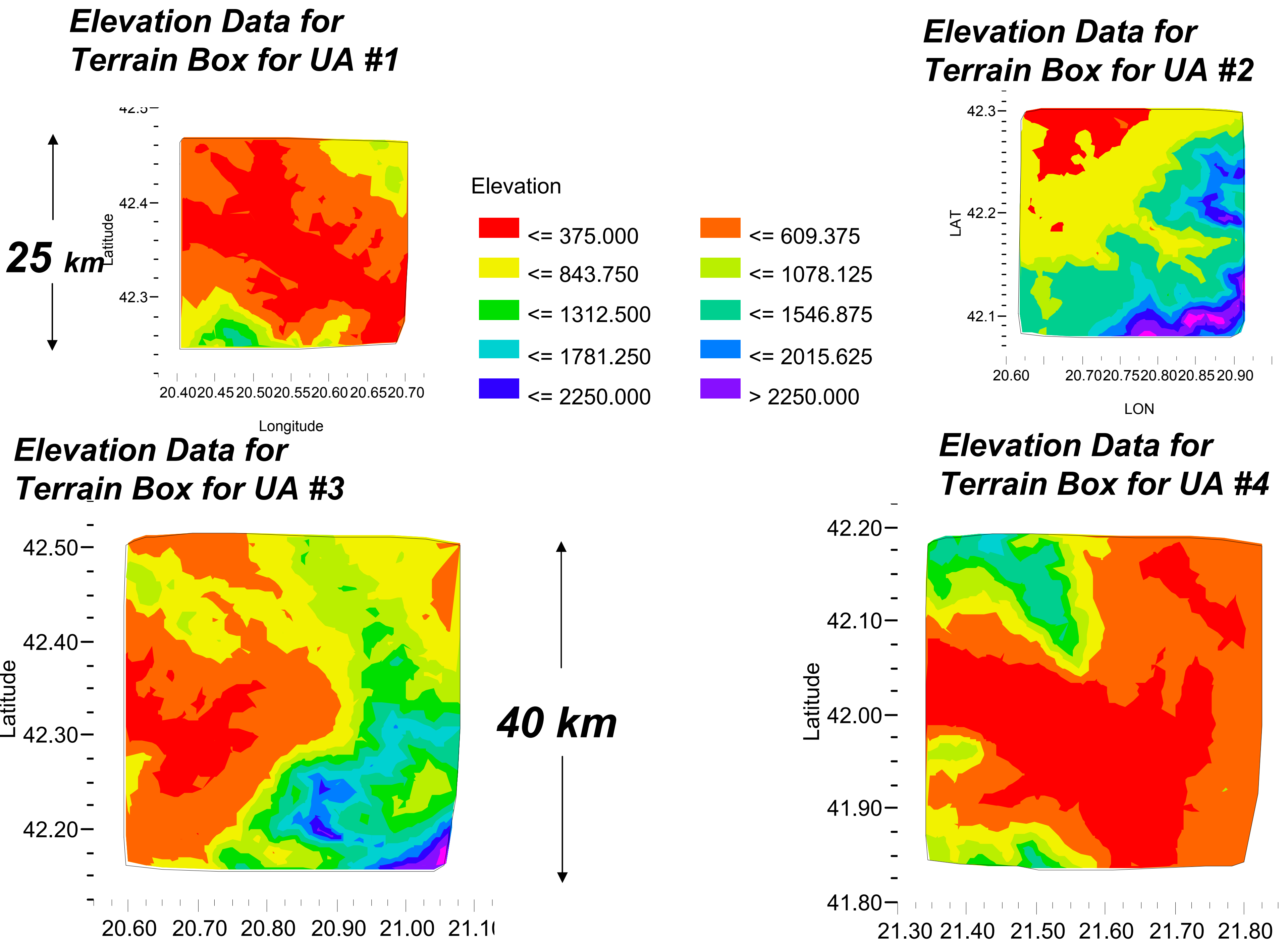
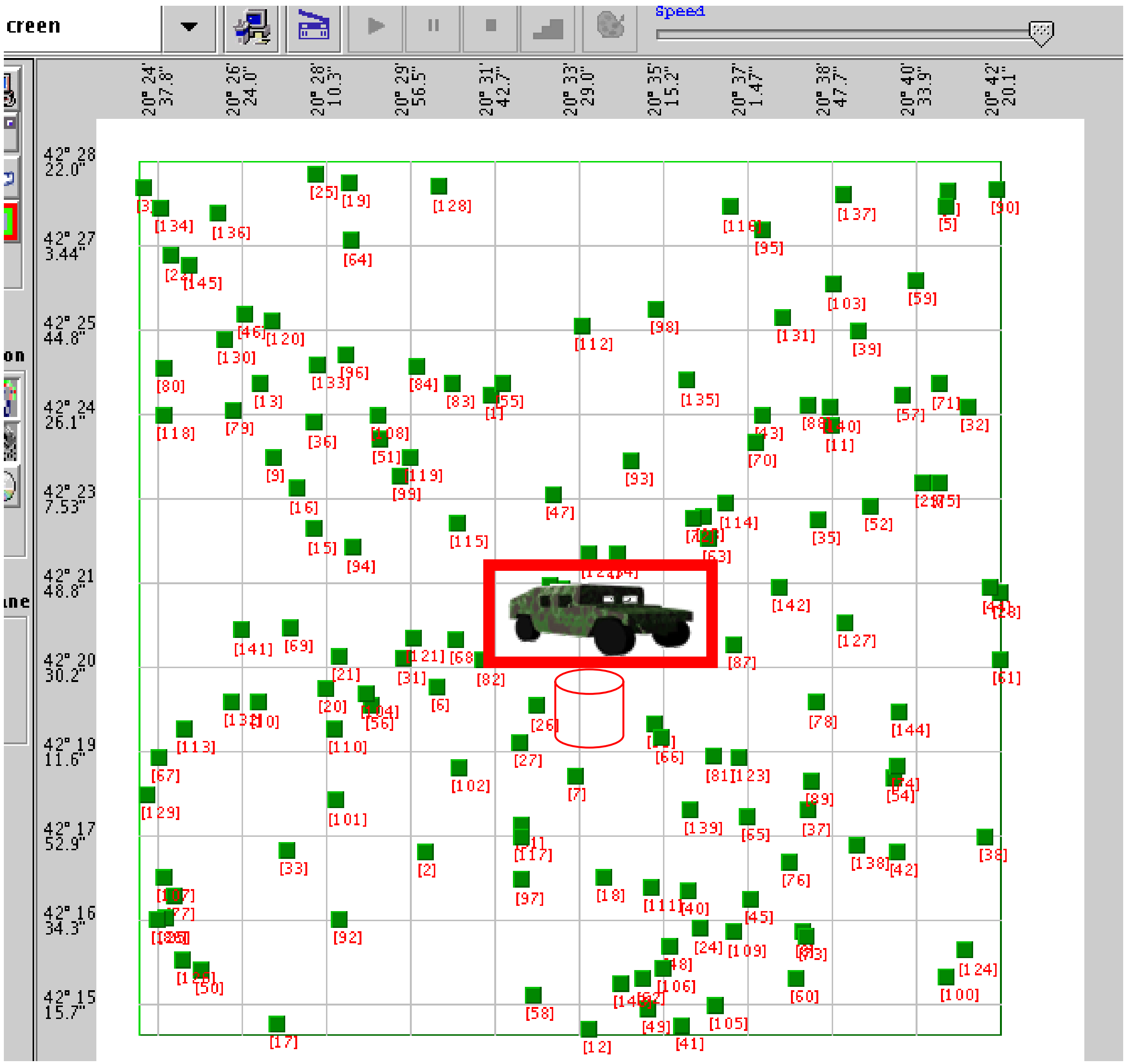
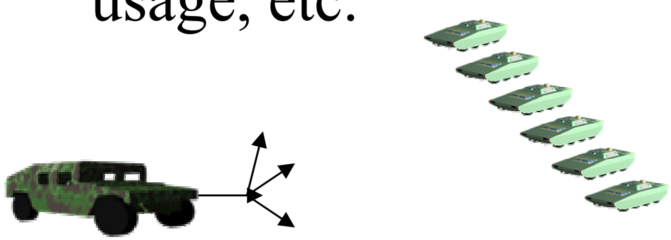

Elevation Data for Terrain Box for UA #1
25 km
Latitude
42.4
42.3
20.40
20.45
20.50
20.55
20.60
20.65
20.70
Longitude
Elevation
<= 375.000
<= 609.375
<= 843.750
<= 1078.125
<= 1312.500
<= 1546.875
<= 1781.250
<= 2015.625
<= 2250.000
> 2250.000
Elevation Data for Terrain Box for UA #2
LAT
42.3
42.2
42.1
20.60
20.70
20.75
20.80
20.85
20.90
LON
Elevation Data for Terrain Box for UA #3
Latitude
42.50
42.40
42.30
42.20
20.60
20.70
20.80
20.90
21.00
40 km
Elevation Data for Terrain Box for UA #4
Latitude
42.20
42.10
42.00
41.90
41.80
21.30
21.40
21.50
21.60
21.70
21.80

Example Of Simulation Experiments (Area #1)



Experiment:

- Bn-light dispersed across Terrain
- Data multicasted out to nodes at varying rate
- Performance captured as function of frequency, mobility, UAV usage, etc.



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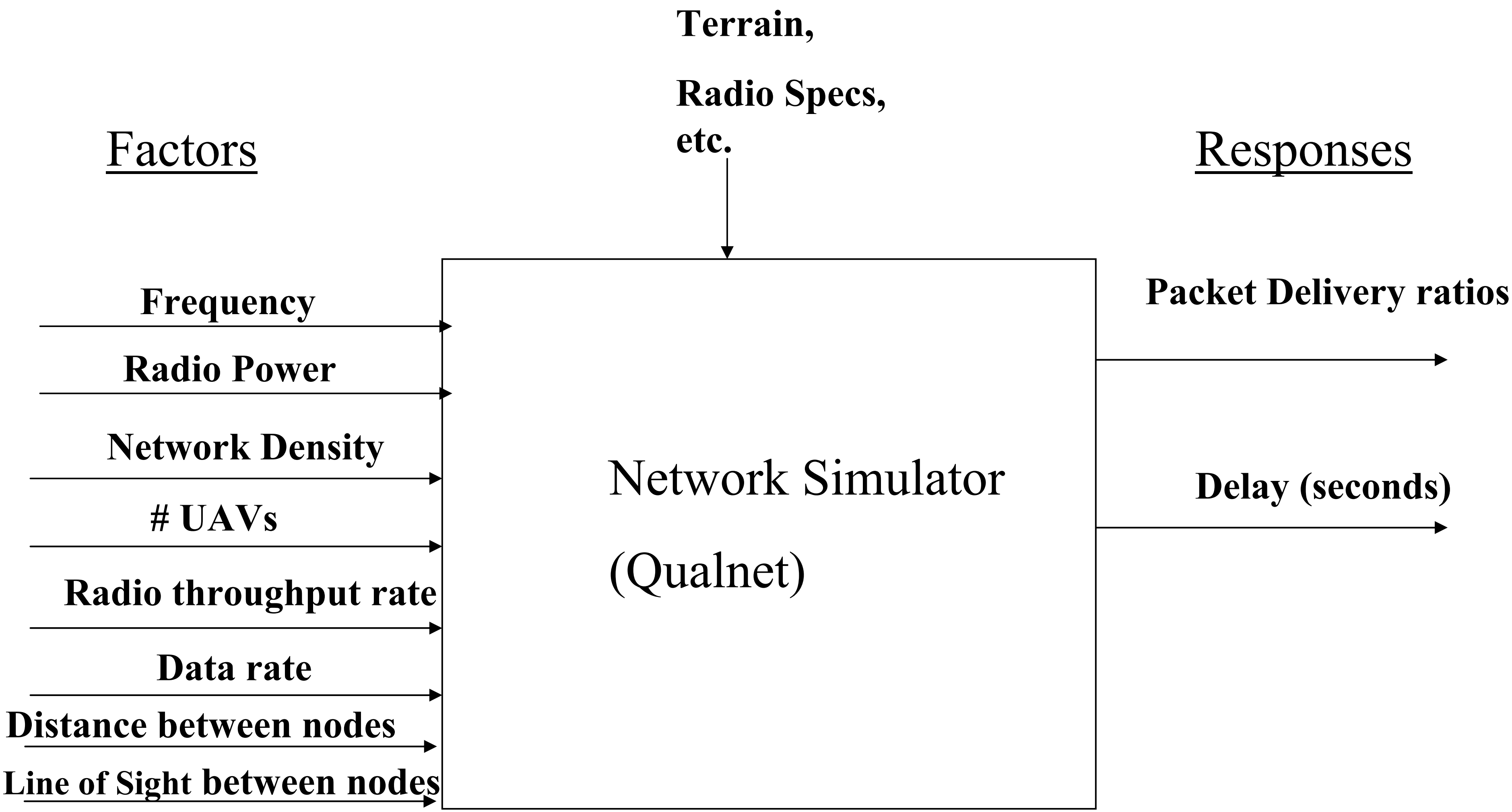
Data out to all

Factors of Interest and Responses



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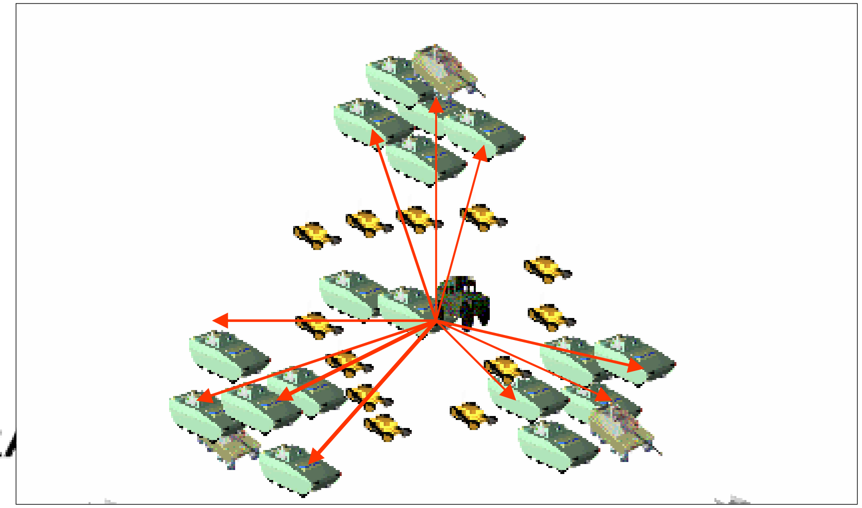
Design of Experiments: Simulations Run at Various Levels of Each Factor

Design Matrix

Sim run	freq	# UAVs	Pwr	Density (nodes)	Radio Cap	Ant. Hgt	Deli very	Delay
1	2GHz	0	20W	145	6Mbps	2.5m	%	sec
2	1 GHz	8	20W	72	6Mbps	5 m		
3	.4 GHz	4	20W	36	2Mbps	10 m		
4	2 GHz	0	20W	145	2Mbps	2 m		
5	1GHz	8	20W	72	2Mbps	5 m		



1000-3000 Experiments
Run for each Area

Closed Form Expression Developed to Capture Performance as Function of Demand for UA level

$$\text{Logit (pdr)} = \beta_0 +$$

$$\beta_1(\text{Frequency}) + \beta_2(\text{UAVs}) + \ldots$$

Other First-Order Terms

$$\beta_3(\text{Frequency} \times \text{UAVs}) + \ldots$$

Other Second-Order Terms

Other Higher Order Interactions

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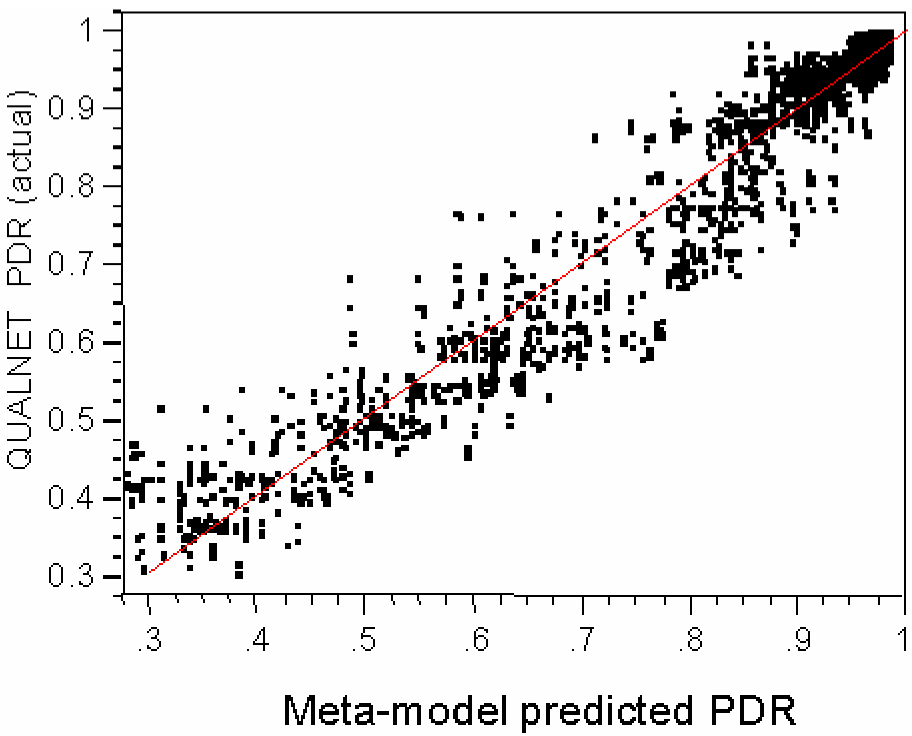
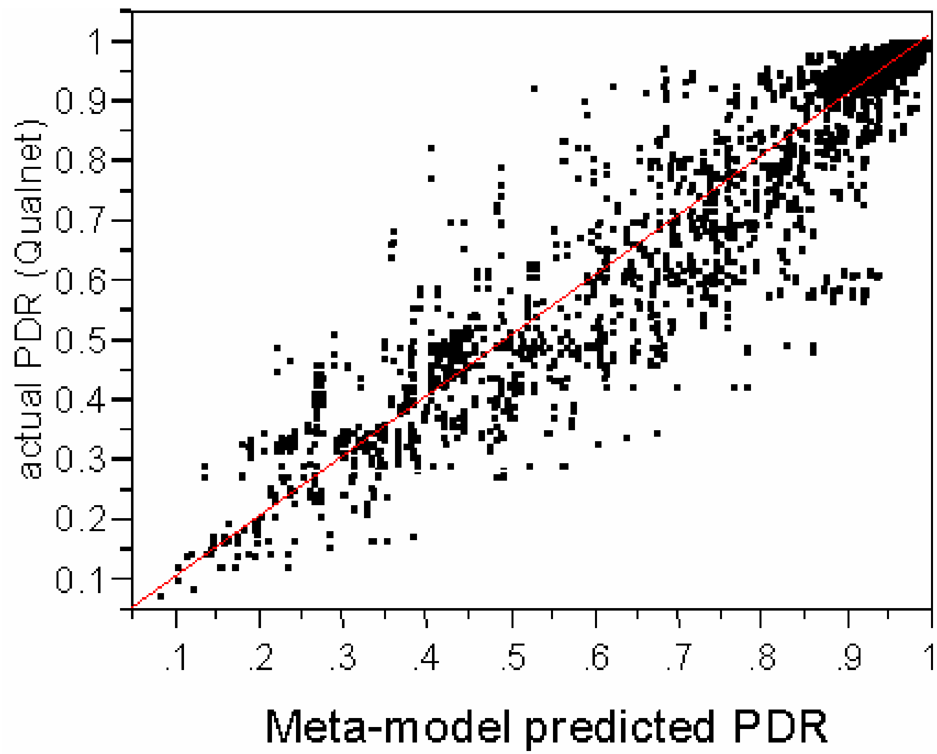
Evaluating The Fit For One Measure





Logit(p)=f(frequency, # UAVs, density, data traffic, distance..)

$$\text{pdr} = \frac{\exp(\log it(p))}{(\exp(\log it(p)) + 1}$$

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Evaluating The Fit (Cont.)

Table: Evaluating the fits for 2-way parameter interaction

Area/ Equation	Adjusted R-Square Value for PDR	Adjusted R-Square Value for Delay
1	0.715	0.755
2	0.749	0.817
3	0.725	0.813
4	0.706	0.800

Note: The fits can be improved by representing more than two-way parameter interaction in the model.

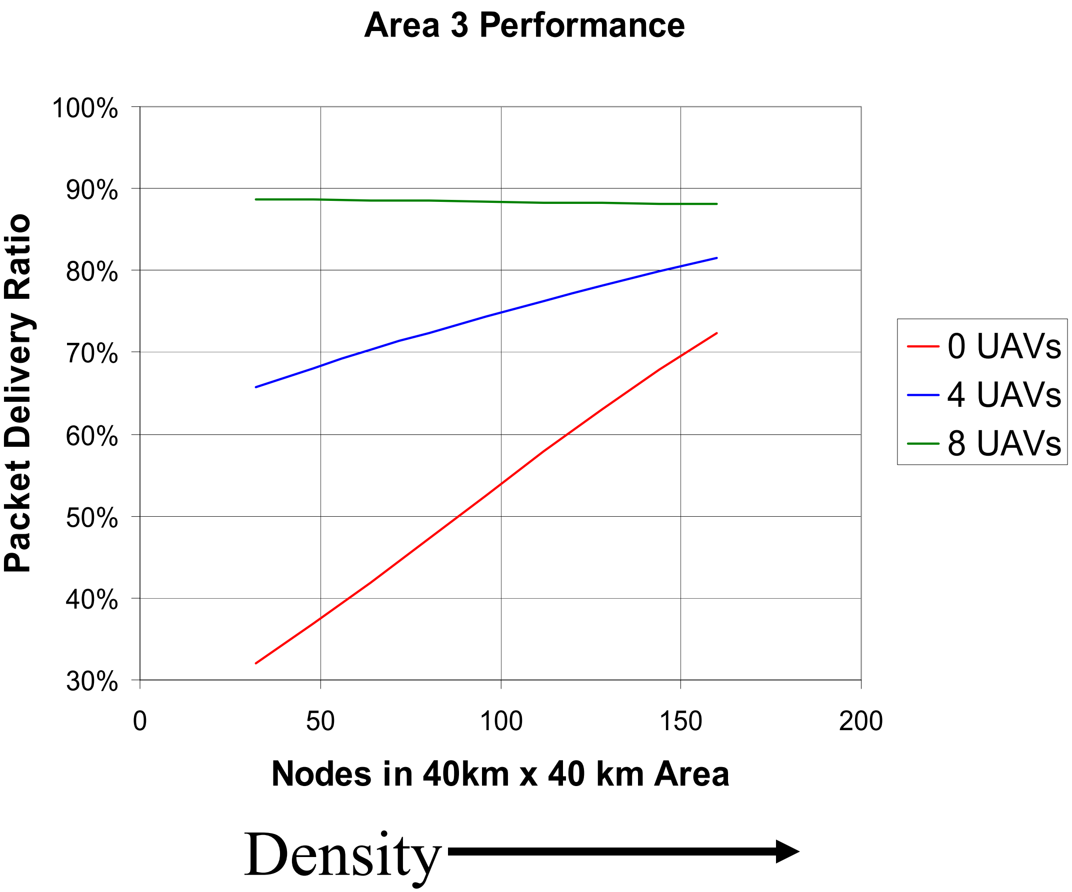
Evaluating The Fit (Cont.)

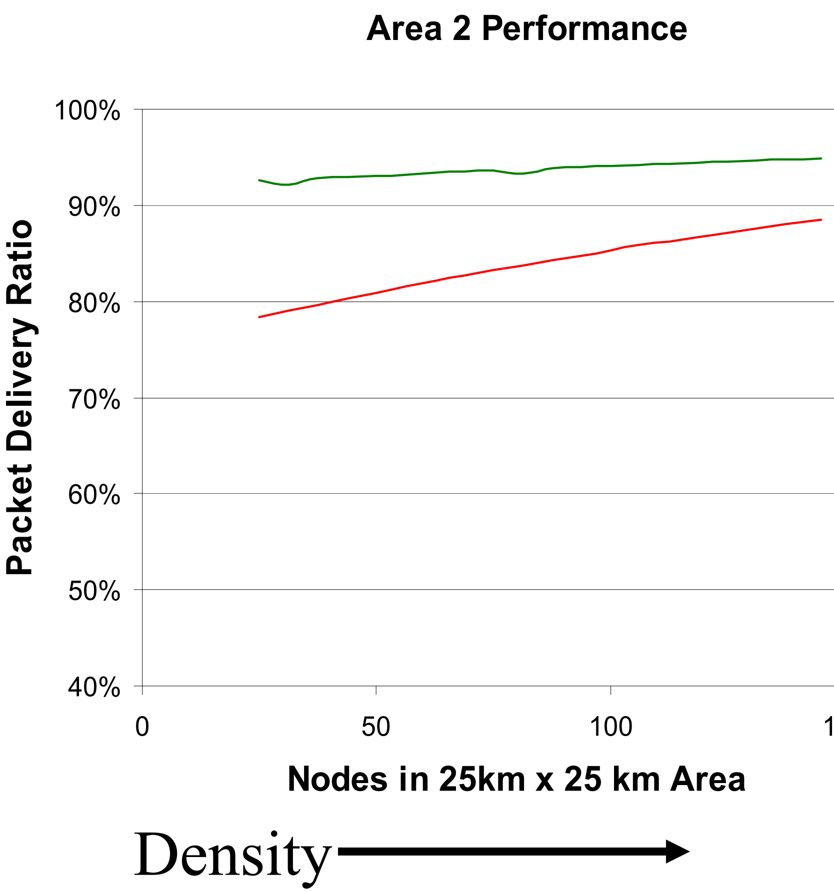
Table: Evaluating the Fits for 4-way Parameter Interaction

Area Equation	Adj. R-Square Value for PDR	Adj. R-Square Value for Delay	Adj. R-Square Value for PDR, LOS	Adj. R-Square Value for Delay, LOS
1	0.72	0.78	-	-
2	0.75	0.84	0.77	0.85
3	0.73	0.84	0.78	0.86
4	0.71	0.82	-	-

Some Analysis Results Using The Metamodels

Benefit of UAVs Depends on Density of Forces





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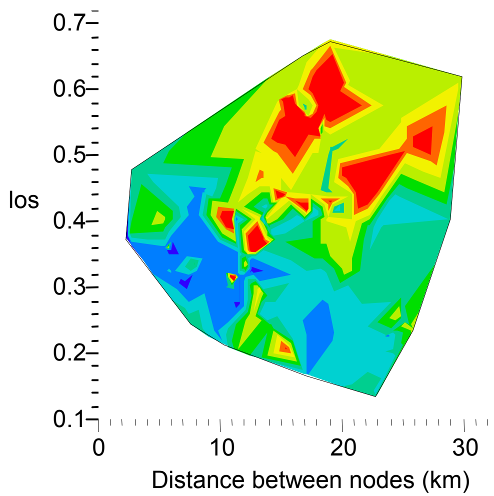
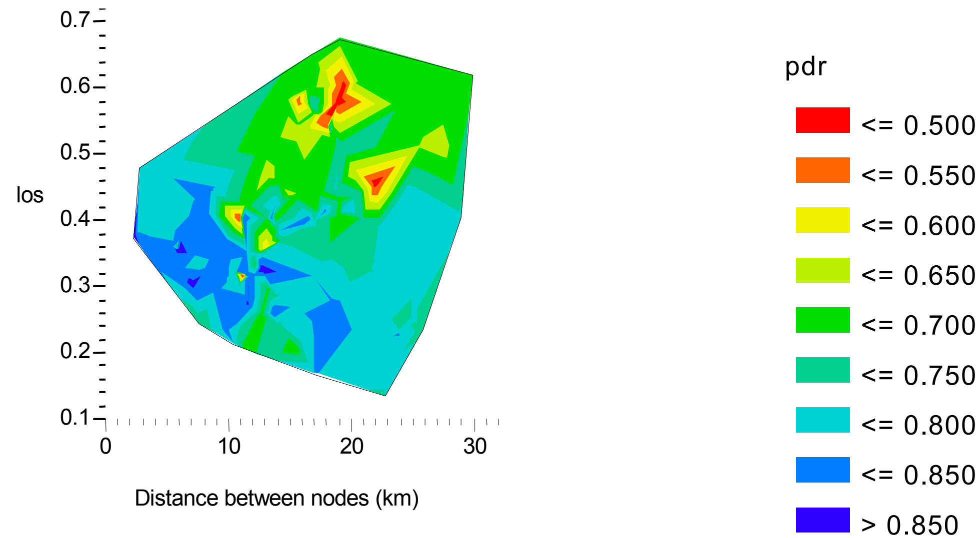
Results are Robust Across Terrain

Example Analysis Facilitated by M&S: Impact of UAVs Quantified



Performance with 0 UAVs (packet delivery ratio) given distance and line-of-sight measure for Area 3



Performance with 8 UAVs (packet delivery ratio) given distance and line-of-sight measure for Area 3

Plot of Packet Delivery Ratio Between Nodes as a Function of Line-of-Sight and Distance

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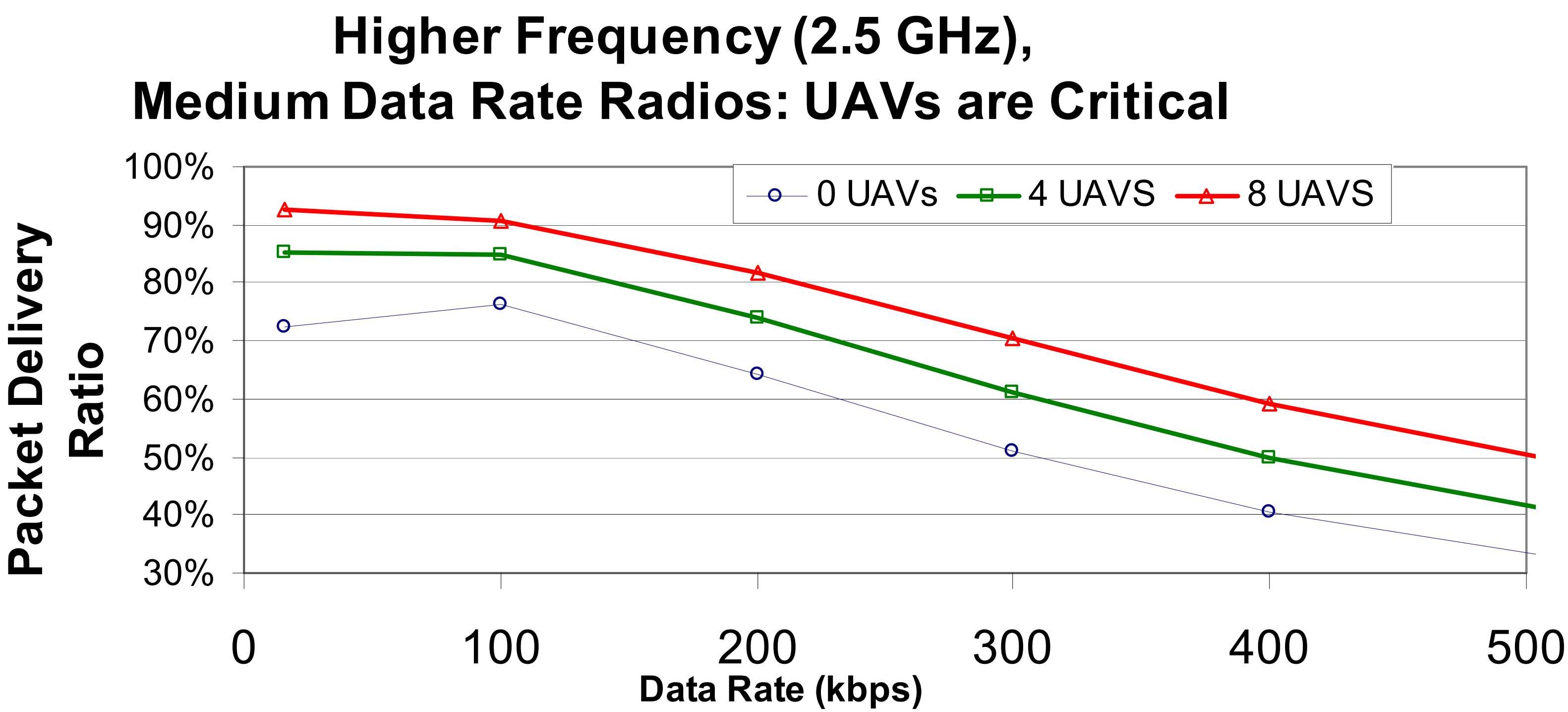
UAVs Improve Performance Across Data Rates



Observation from Model: A Large Number of Verticle Nodes Needed to Ensure 25km x 25km Area (For Certain Frequency Channels)

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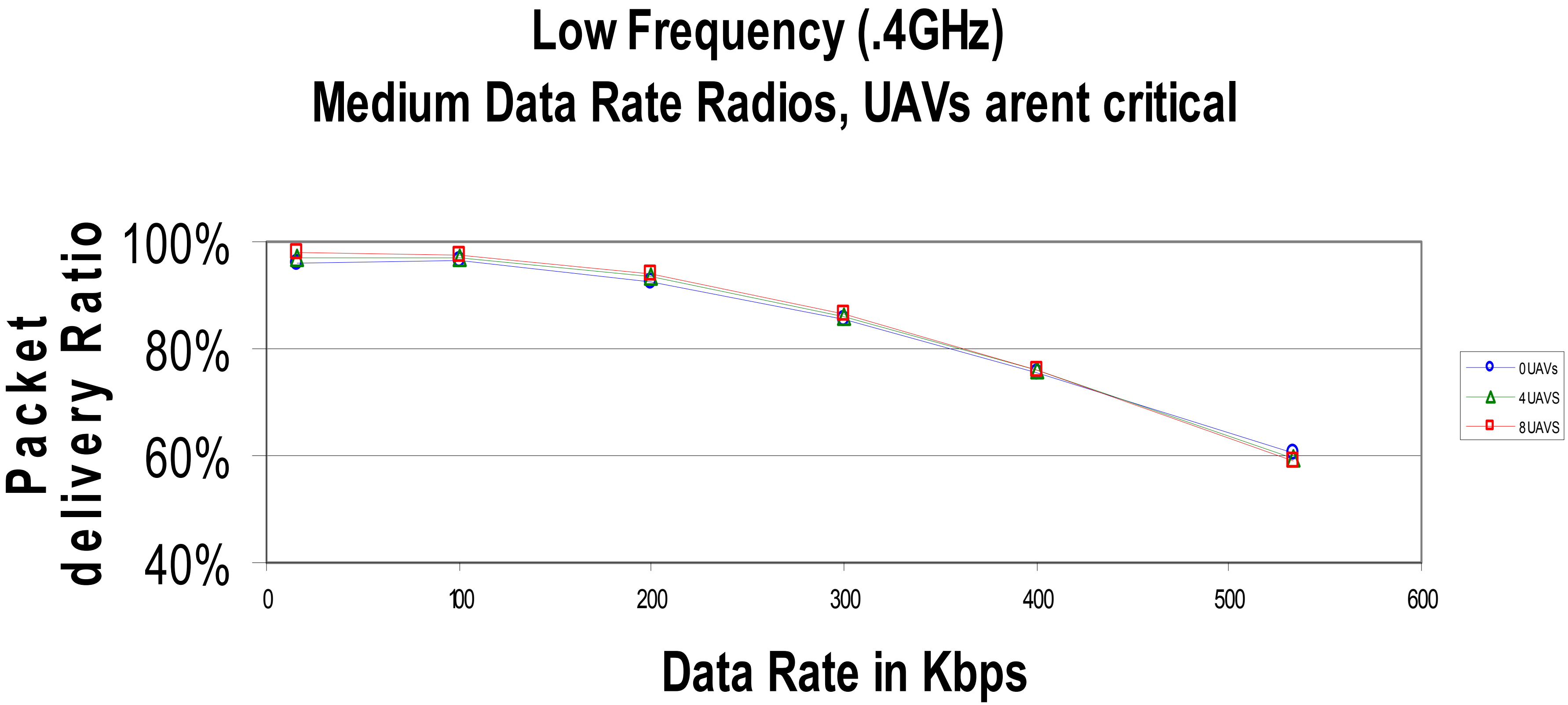
But Greater Gains Achieved At Better Propagating Frequencies



"Better"Channel allocation Requires Fewer UAVs to Maintain High performance

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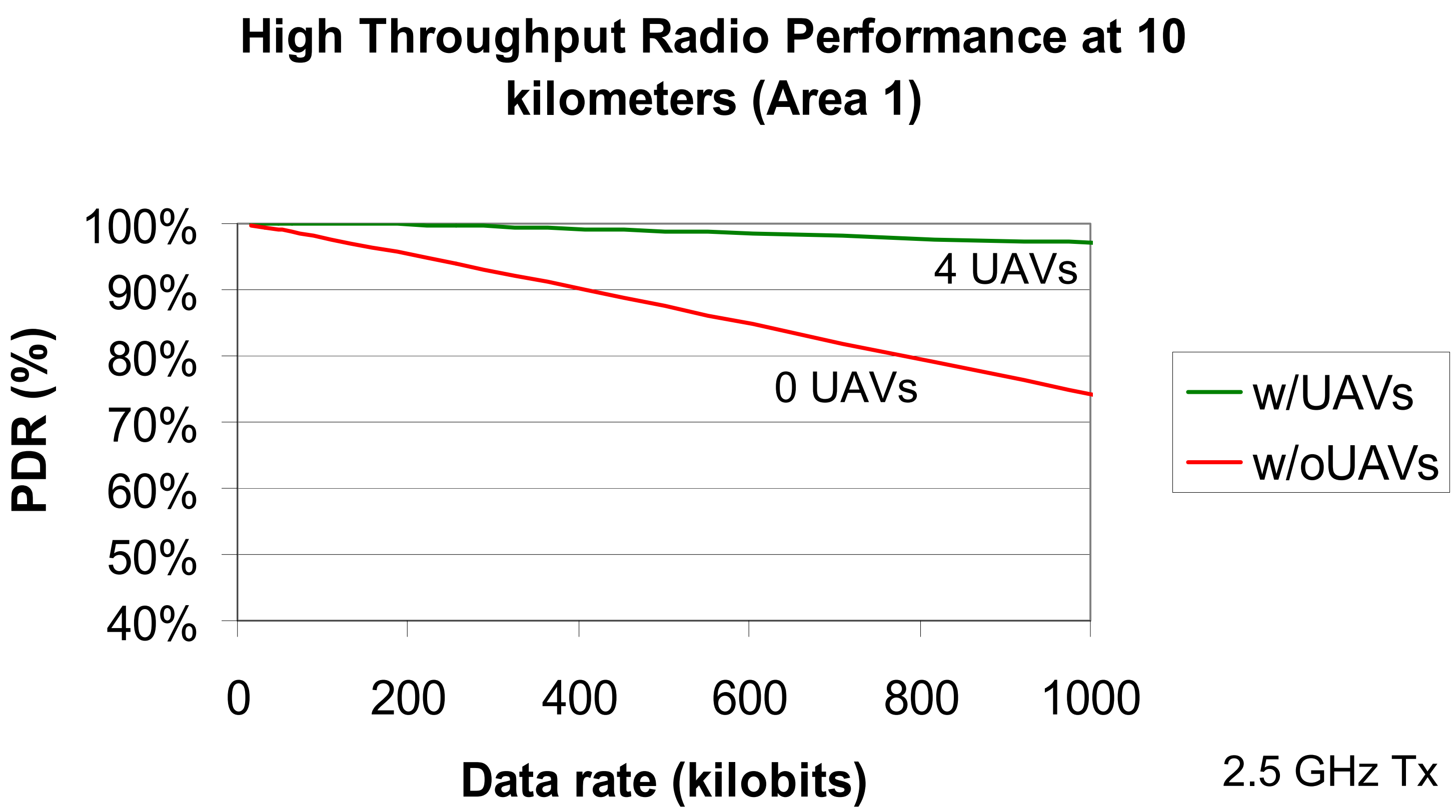
Better still: High Radios (6 Mbps) JTRS Radios Provide Big Performance Enhancement

For example:



<u>145</u> Node network in 25km x 25km area with 6Mbps Radios

Model of Area 1 Used Above

Observations from Modeling Effort

- High bandwidth tactical radios will help (> 5 Mbps user throughput)
- Near future radios (1-2 Mbps user throughput) will require significant UAV presence to ensure reliable C2/SA network
  - Depending on force size
  - Information dissemination requirements
  - Spectrum to support them a big issue
- Frequency agile, cognitive radios have potential to be advantageous

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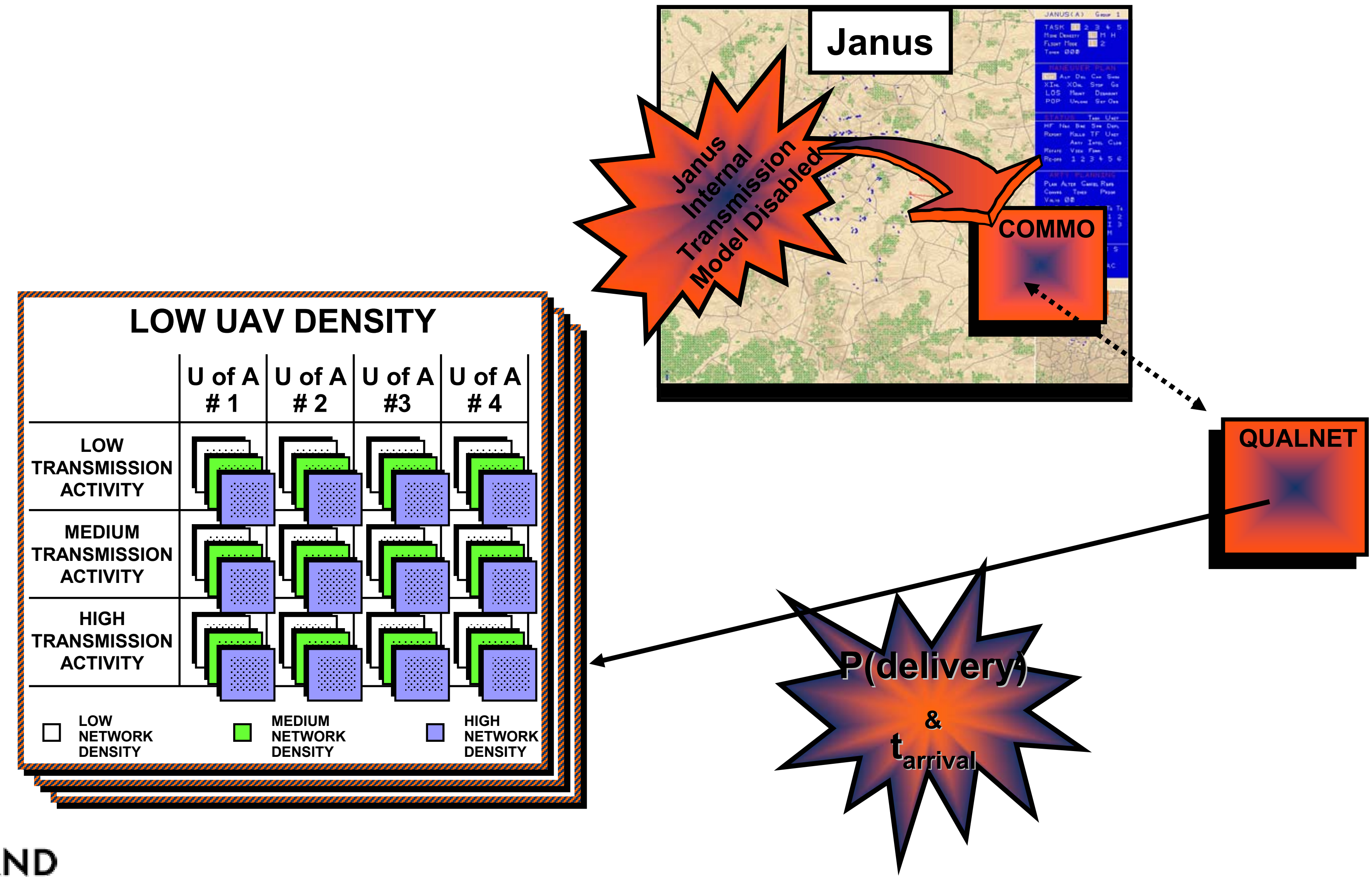
Next Step: QUALNET Derived Data Communication Model Inserted in Combat Simulator



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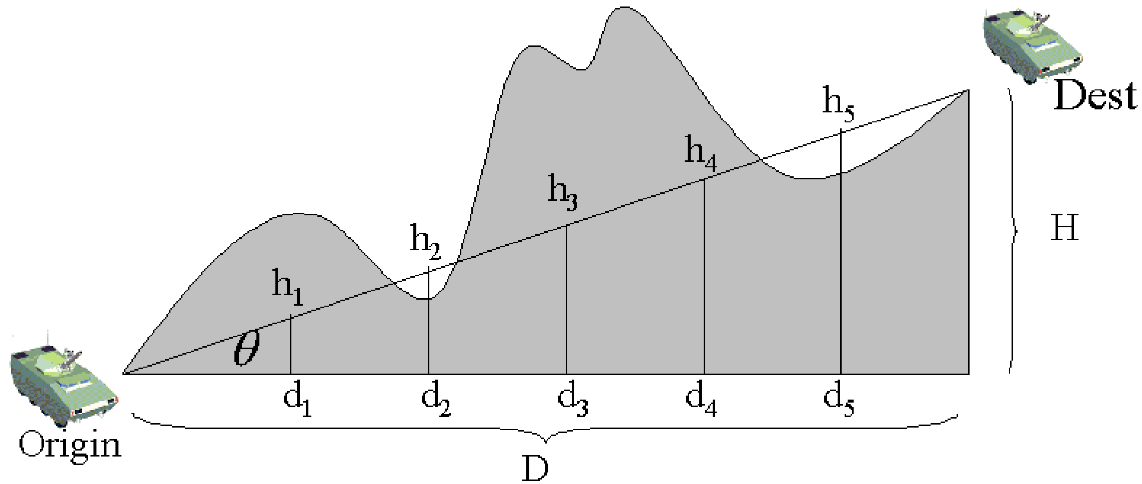
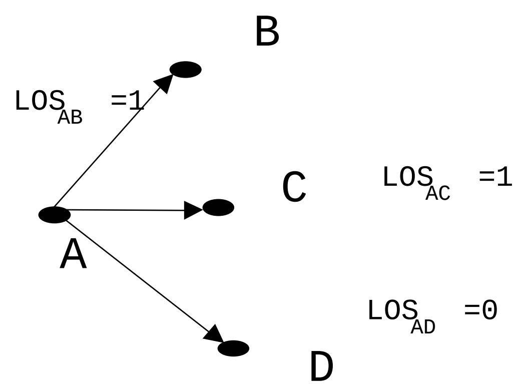
Back-ups

Line of Sight (LOS) Was Useful Factor





$LOS_A = Avg(LOS_{AB}, LOS_{AC}, LOS_{AD}) = 2/3$

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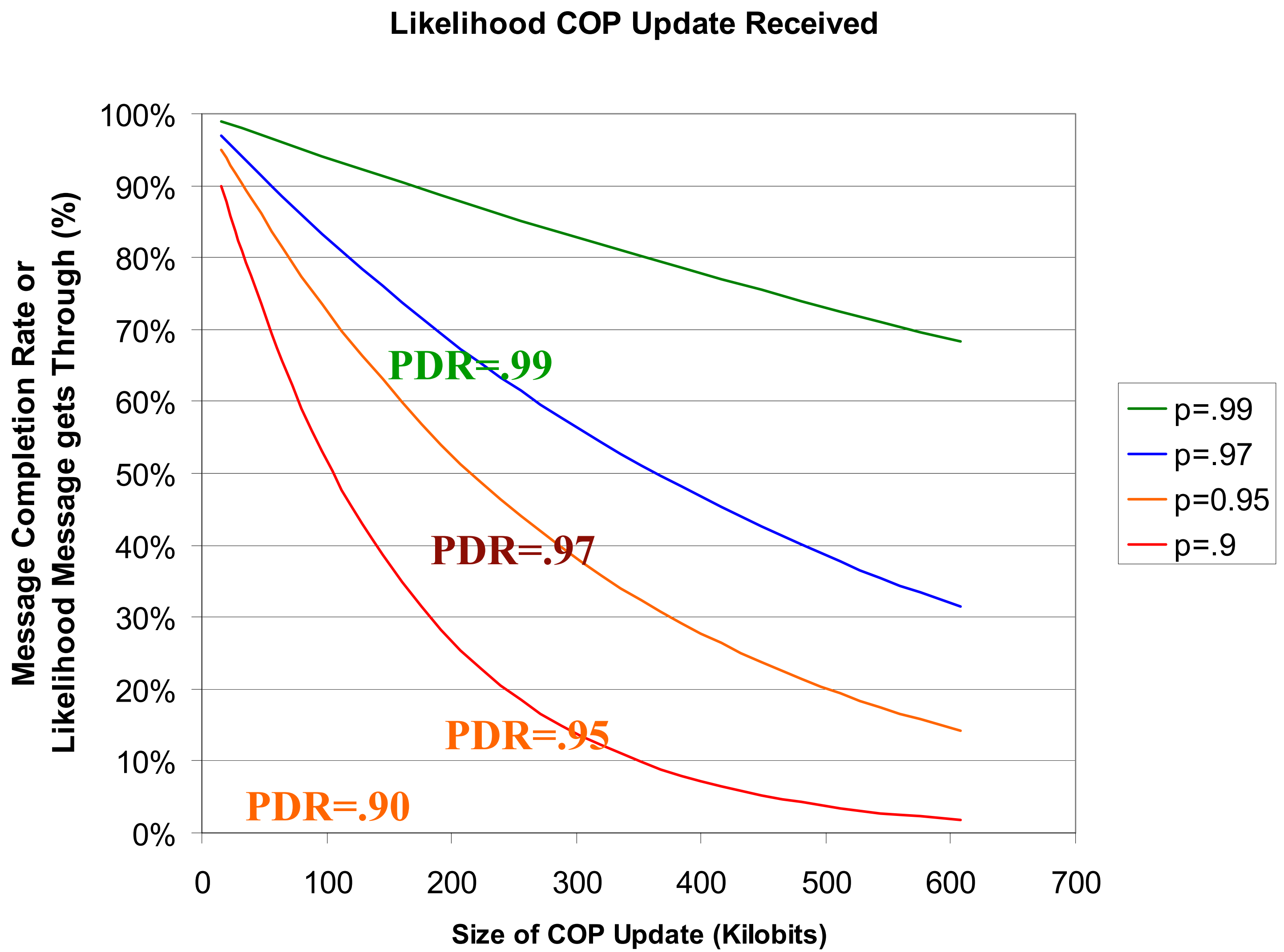
Why Are Packet Requirements So Critical?



Message Completion Rates Highly Sensitive to Packet Delivery Ratios

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Sample of Results From Experiments

Area	# of UAVs	Density Nodes/km^2	Frequency	90% PDR Data Rate
2 (25 x25)	8	.12	2.5 GHz	270 Kbps
2 (25 x25)	4	.12	2.5 GHz	255 Kbps
2 (25 x25)	0	.12	2.5 GHz	240 Kbps
2 (25 x25)	8	.12	0.4 GHz	320 Kbps
2 (25 x25)	4	.12	0.4 GHz	345 Kbps
2 (25 x25)	0	.12	0.4 GHz	375 Kbps
2 (25 x25)	8	.06	2.5 GHz	110 Kbps
2 (25 x25)	4	.06	2.5 GHz	40 Kbps
2 (25 x25)	0	.06	2.5 GHz	-

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