UT-BATTELLE

On The Design and Capacity Of Wide Area Sensor Networks

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U. S. DEPARTMENT OF ENERGY

Outline

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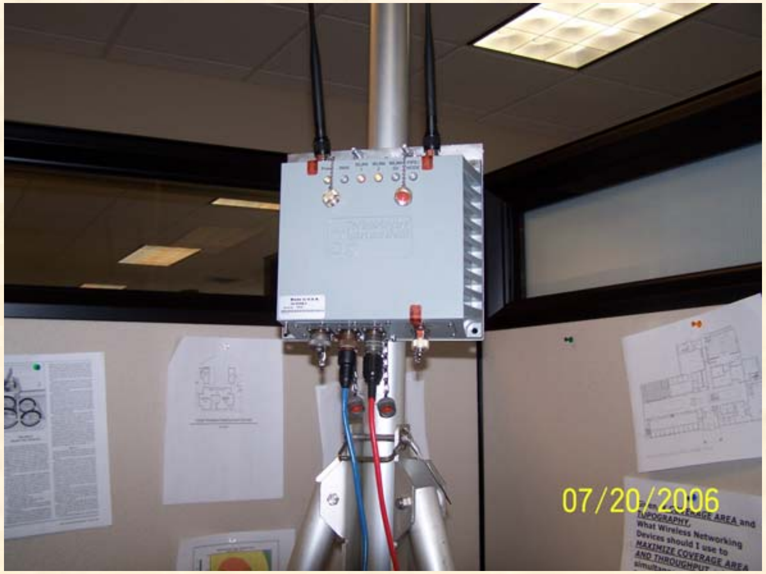
  - **Wireless Sensor Network Context**
  - **SensorNet Deployment and Design Challenge**
- **Methodology**
  - **Background**
  - **Iterative Deployment Steps**
- **Experiments**
  - **Tools**
  - **Measurements at ORNL**
- **Conclusions**
- **Summary and Future Work**

Motivation and Goals

- **Rapid deployment of wireless sensor networks is a critical need**
- **Deployment techniques remain more of an art than a science**
  - Radio propagation environments and path-loss effects are hard to provision for without careful measurement
  - Diverse commercial off the shelf wireless devices have inconsistent behaviors
- **An effective methodology for wireless network deployments will result in full coverage and capacity throughout the monitored zone in the least amount of time.**
  - This methodology will be evaluated as it is applied to an actual SensorNet deployment scenario at ORNL

SensorNet Component Examples

An ORNL-developed system responsible for collecting CBRNE (and other environmental) sensor data and distributing it back to the appropriate authority



Access Point

Radiation and Chemical Agent Detectors

Design Problem

- **Network coverage must blanket the entire monitored space**
- **Ensure network provides full capacity to all sensor nodes**
- **Received signal must not unexpectedly attenuate to an unusable level with increasing distance from the transmitter**
- **Each transmitter within a multi-transmitter network must communicate over non-interfering channels**
- **Hurdles to Overcome :co-channel interference, hidden and exposed terminal phenomena, multi-path fading effects at the receiver**

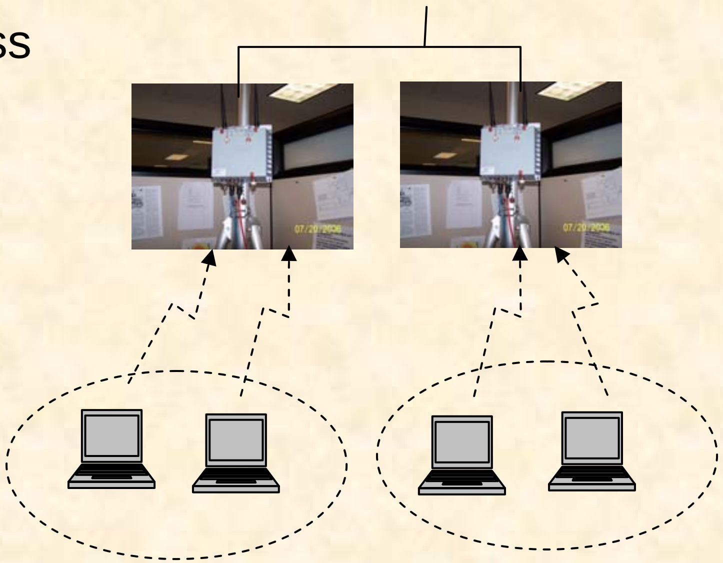
Focus on Infrastructure Wireless Network

Advantages:

- All traffic from client devices flow through access point
- Access point manages topology
- The client stations do not overload the network with internodal routing protocols
- Closer to realistic deployments

Disadvantages:

- Mobility limited by range of the access point
- Single point of network failure if the access point fails, all client/sensor nodes associated with the AP loose global connectivity



Summer experiments focused on 802.11b Protocol – Infrastructure Mode

Sensor Placement to Track Threats

- Deploy sensors in an X-pattern along each leg to track movement
- Space sensors evenly at 5 meter intervals
- Sensor distribution simplified for line-of-sight deployments
  (limited multi-path effects considered)

Fig. 1 ORNL East-Campus Quad

A Systematic Deployment Process

Pre-deployment

1. Determine the total area of the proposed monitored zone

2. Determine the typical coverage area of an access point transmitting at <u>maximum power</u>

3. Initially deploy access points and sensors to spatially cover the target area

Fig. 1 ORNL East-Campus Quad

A Systematic Deployment Process

Environment Characterization

1. Measure initial signal coverage area of each AP

2. Characterize the noise floor at each initial AP and sensor position for each proposed network channel

3. Characterize the terrain between the transmitters and receivers and simulate the effect on the RF signal

Fig. 1 ORNL East-Campus Quad

A Systematic Deployment Process

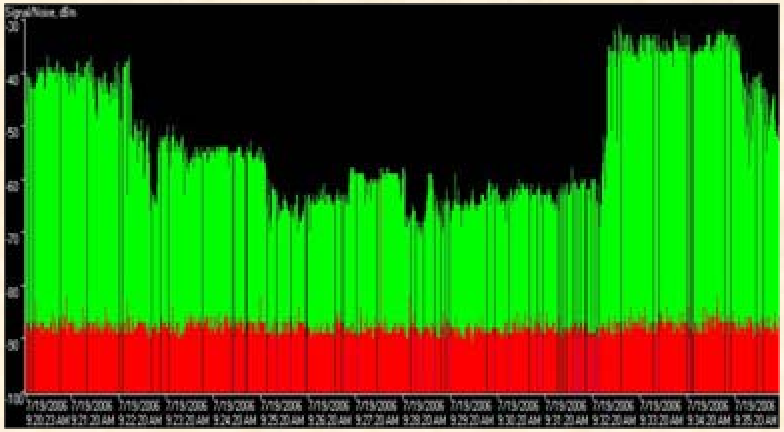
Simulation and Validation

- Observe current RF coverage and capacity profile within the simulator. -which are based on initial measured values-
- If desired coverage and capacity is not achieved then virtually move AP's to new positions until optimum coverage and capacity is achieved within the simulation
- If the simulated received signal values are acceptable, manually move AP's and sensors into their final positions. Otherwise iterate over previous steps.
- Take a final set of signal measurements to validate the simulator's results
- Finally, document current signal and noise levels at AP and sensor locations for continued network maintenance and future expansion

Fig. 1 ORNL East-Campus Quad

Netstumbler Measurements

- **Analysis software**
  - **802.11x network evaluation**
  - **Commercial tool (*http://www.netstumbler.com*)**
- **Measurements**
  - **Choose theoretical model**
  - **Validate and refine coverage choice**



Netstumbler Raw Data

SSID	BSSID	Time hh:mm:ss	Distance from TX (m)	Direction from AP	NS RX Signal (dbm)	NS SNR	NS Noise (dbm)	NS Channel	TLM PL test points
Sensornetzz	00:0b:6b:35:fd:15	19:46:41	1	West	-29	60	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	19:48:18	5	West	-49	39	-88	11	pt1
Sensornetzz	00:0b:6b:35:fd:15	19:49:13	10	West	-39	50	-89	11	pt2
Sensornetzz	00:0b:6b:35:fd:15	19:49:54	15	West	-40	49	-89	11	pt3
Sensornetzz	00:0b:6b:35:fd:15	19:50:42	20	West	-47	43	-92	11	pt4
Sensornetzz	00:0b:6b:35:fd:15	19:51:36	25	West	-49	41	-90	11	pt5
Sensornetzz	00:0b:6b:35:fd:15	19:52:26	30	West	-50	40	-90	11	
Sensornetzz	00:0b:6b:35:fd:15	19:53:42	1	East	-33	55	-88	11	pt6
Sensornetzz	00:0b:6b:35:fd:15	19:54:57	5	East	-38	49	-87	11	pt7
Sensornetzz	00:0b:6b:35:fd:15	19:56:30	10	East	-44	45	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	19:57:11	15	East	-41	48	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	19:57:47	20	East	-41	45	-86	11	
Sensornetzz	00:0b:6b:35:fd:15	19:58:39	25	East	-43	44	-87	11	
Sensornetzz	00:0b:6b:35:fd:15	19:59:40	30	East	-53	36	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:00:55	1	South	-26	63	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:01:47	5	South	-49	40	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:02:37	10	South	-43	46	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:03:27	15	South	-52	38	-90	11	
Sensornetzz	00:0b:6b:35:fd:15	20:04:13	20	South	-51	39	-90	11	
Sensornetzz	00:0b:6b:35:fd:15	20:04:13	25	South	-51	39	-90	11	
Sensornetzz	00:0b:6b:35:fd:15	20:06:20	30.692	South	-65	22	-87	11	
Sensornetzz	00:0b:6b:35:fd:15	20:13:09	1	North	-33	56	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:14:06	5	North	-38	49	-87	11	
Sensornetzz	00:0b:6b:35:fd:15	20:15:03	10	North	-37	52	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:16:15	15	North	-42	47	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:17:14	20	North	-46	43	-89	11	
Sensornetzz	00:0b:6b:35:fd:15	20:18:13	25	North	-44	47	-91	11	
Sensornetzz	00:0b:6b:35:fd:15	20:19:01	30	North	-44	46	-90	11	

Measured Path Loss Comparison with Empirically Modeled Path Loss

Path-Loss Models

– Log-Distance

$$\overline{PL}(dB) = PL(d_o) + 10nLog(d / d_0)$$

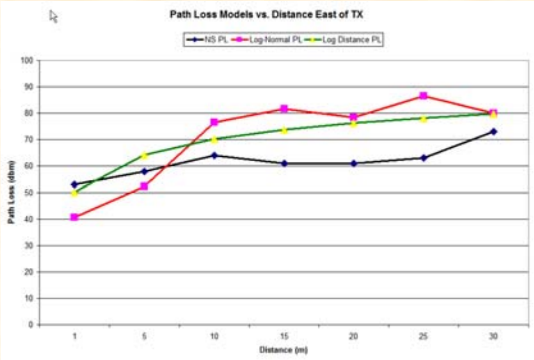
- n = path loss exponent which indicates the rate at which the path loss increases with distance
- d_0 = the close-in reference distance

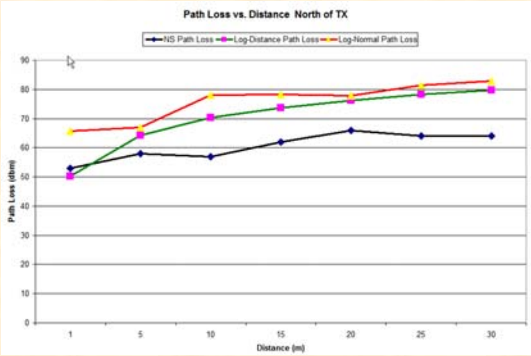
– Log-Normal

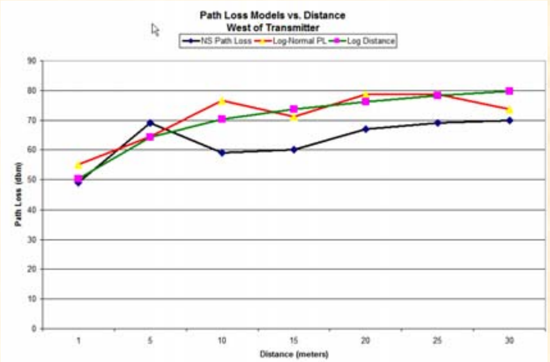
$$\overline{PL}(dB) = PL(d_o) + 10nLog(d / d_0) + X_{stdev}$$

- n = the path loss exponent which indicates the rate at which the path loss increases with distance
- d_0 = the close-in reference distance determined by measurement

- n = 2 for free-space environments
- d_0 = the close-in reference distance 1-meter



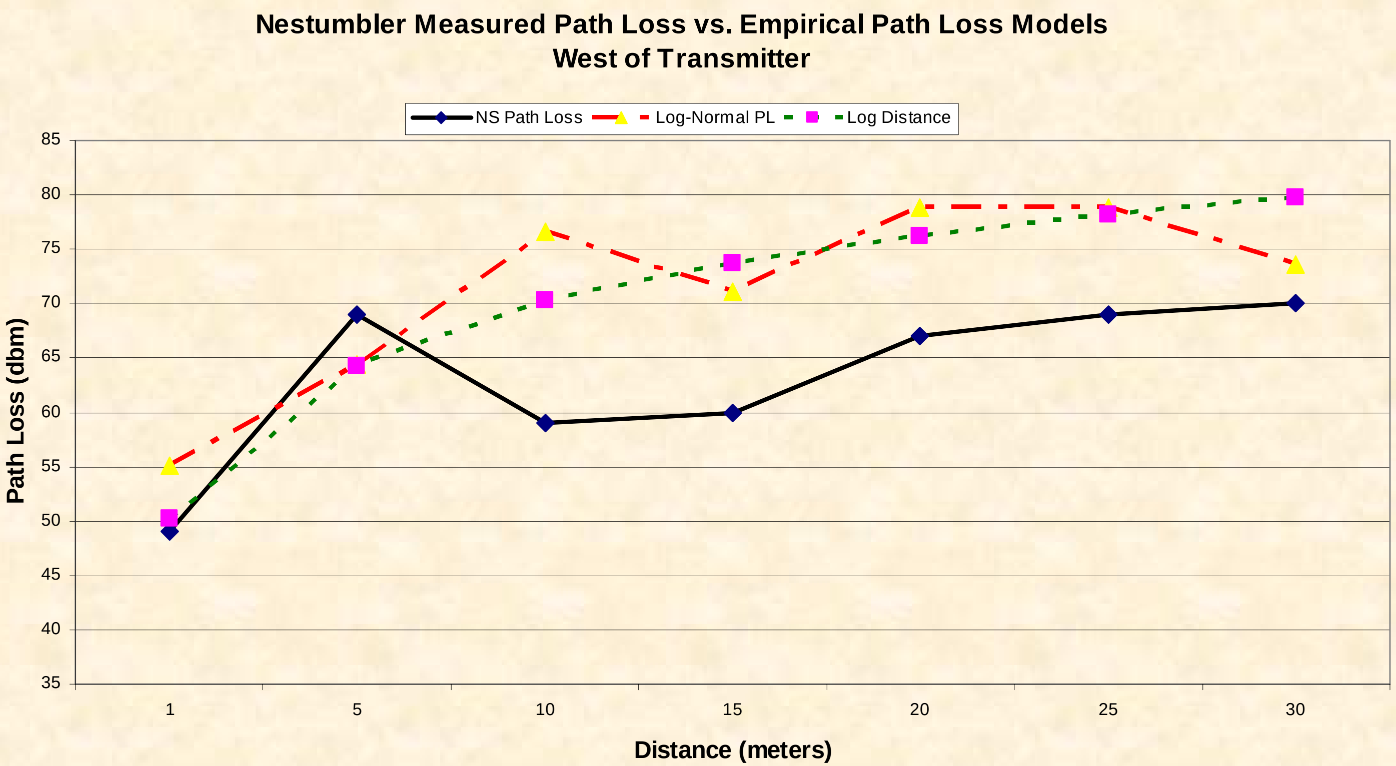




Visual Representation of Results

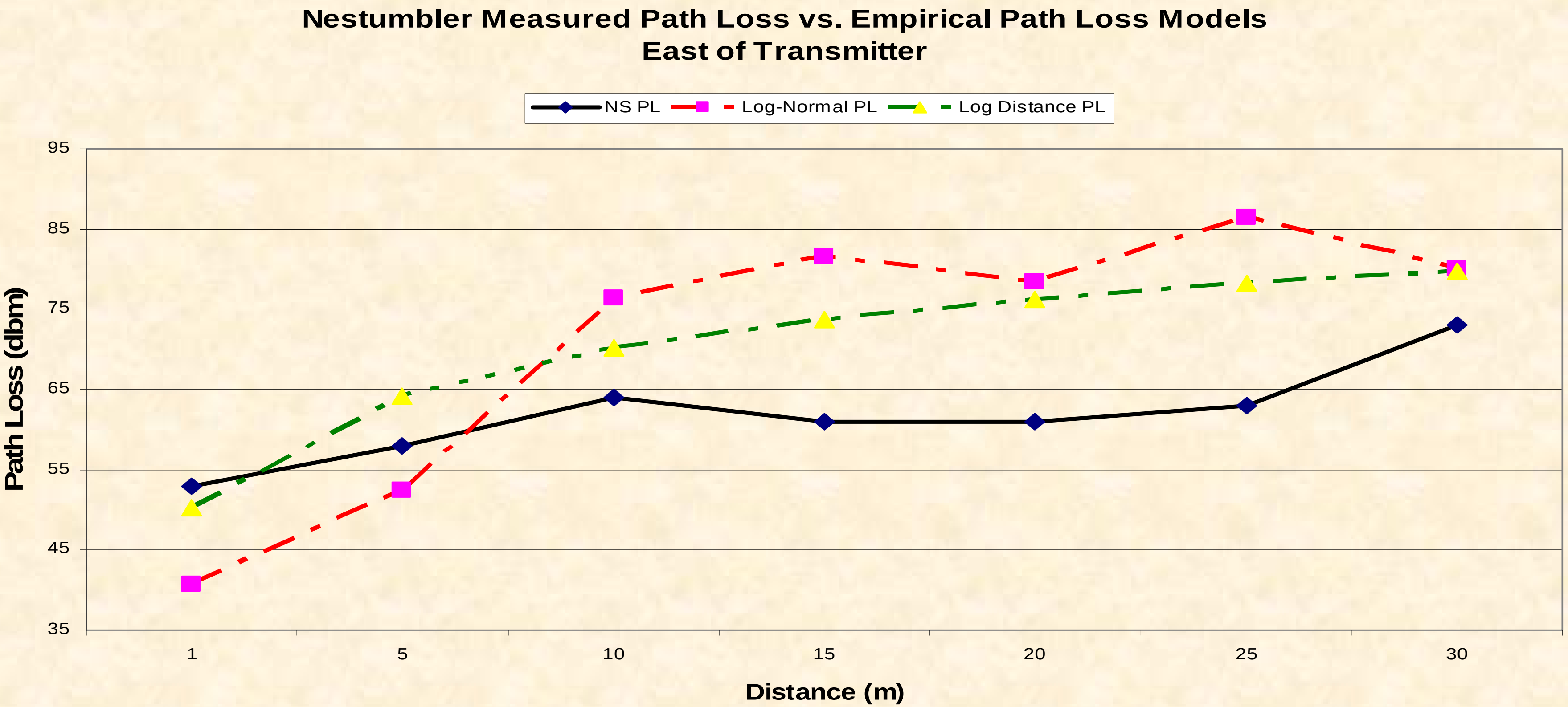
Visualization of Wireless SensorNet Deployment

Nestumbler Measured Path Loss vs. Empirical Path Loss Models



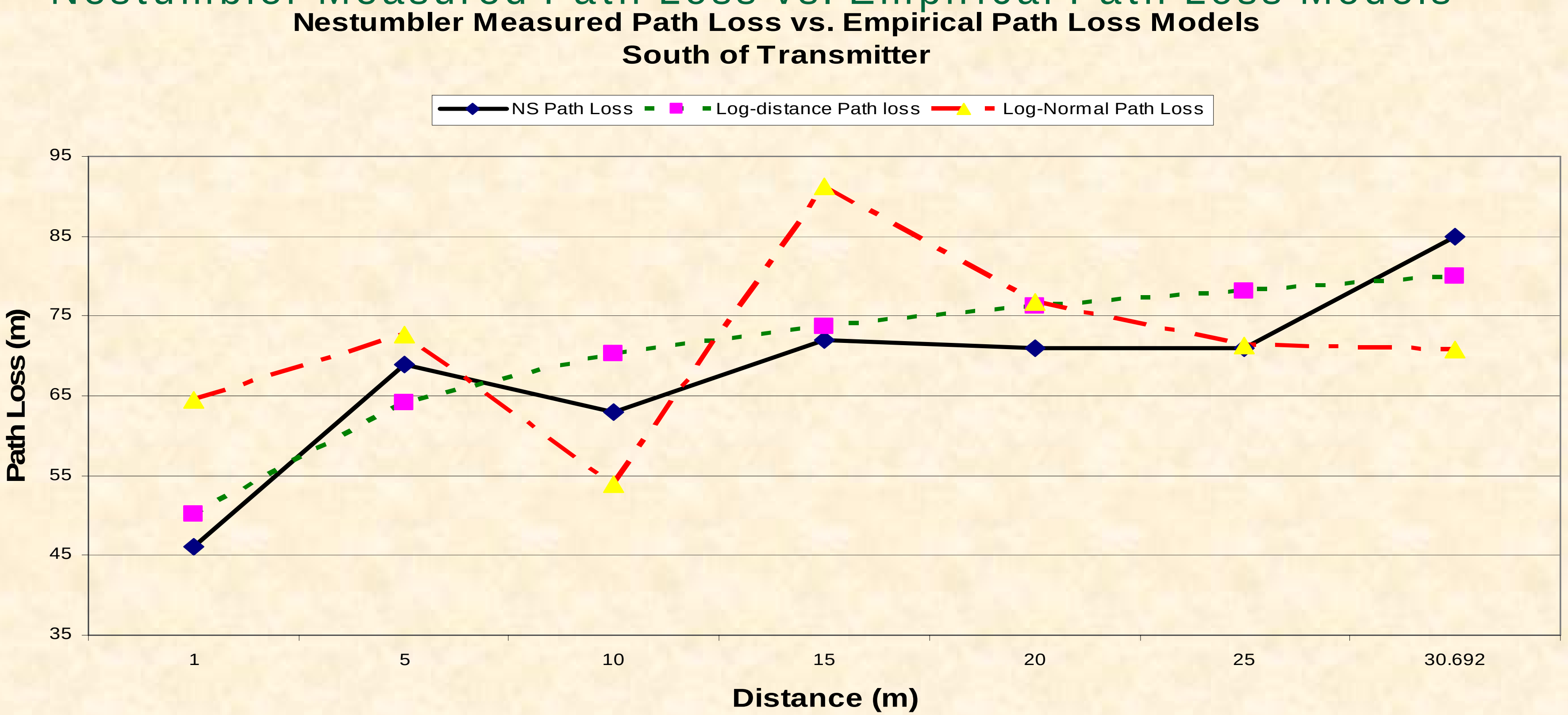
Distance from TX (m)	Direction from AP	NS RX Signal Dbm	TX dbm	NS Path Loss	Log-Distance AvgPL (dbm) (n=2)	Log-normal Shadowing	X_0
1	West	-29	20	49	50.25	55.100551	4.850551
5	West	-49	20	69	64.2294	64.381576	0.152176
10	West	-39	20	59	70.25	76.633773	6.383773
15	West	-40	20	60	73.77183	71.137395	-2.63443
20	West	-47	20	67	76.2706	78.786635	2.516036
25	West	-49	20	69	78.2088	78.785342	0.576542
30	West	-50	20	70	79.79243	73.612043	-6.18038

Nestumbler Measured Path Loss vs. Empirical Path Loss Models



Distance from TX (m)	Direction from AP	NS RX Signal Dbm	TX dbm	NS Path Loss	Log-Distance AvgPL (dbm) (n=2)	Log-normal Shadowing	X_0
1	East	-33	20	53	50.25	40.615801	-9.6342
5	East	-38	20	58	64.2294	52.437624	-11.7918
10	East	-44	20	64	70.25	76.479005	6.229005
15	East	-41	20	61	73.77183	81.620079	7.848253
20	East	-41	20	61	76.2706	78.459078	2.188478
25	East	-43	20	63	78.2088	86.499061	8.290261
30	East	-53	20	73	79.79243	80.082183	0.289758

Nestumbler Measured Path Loss vs. Empirical Path Loss Models

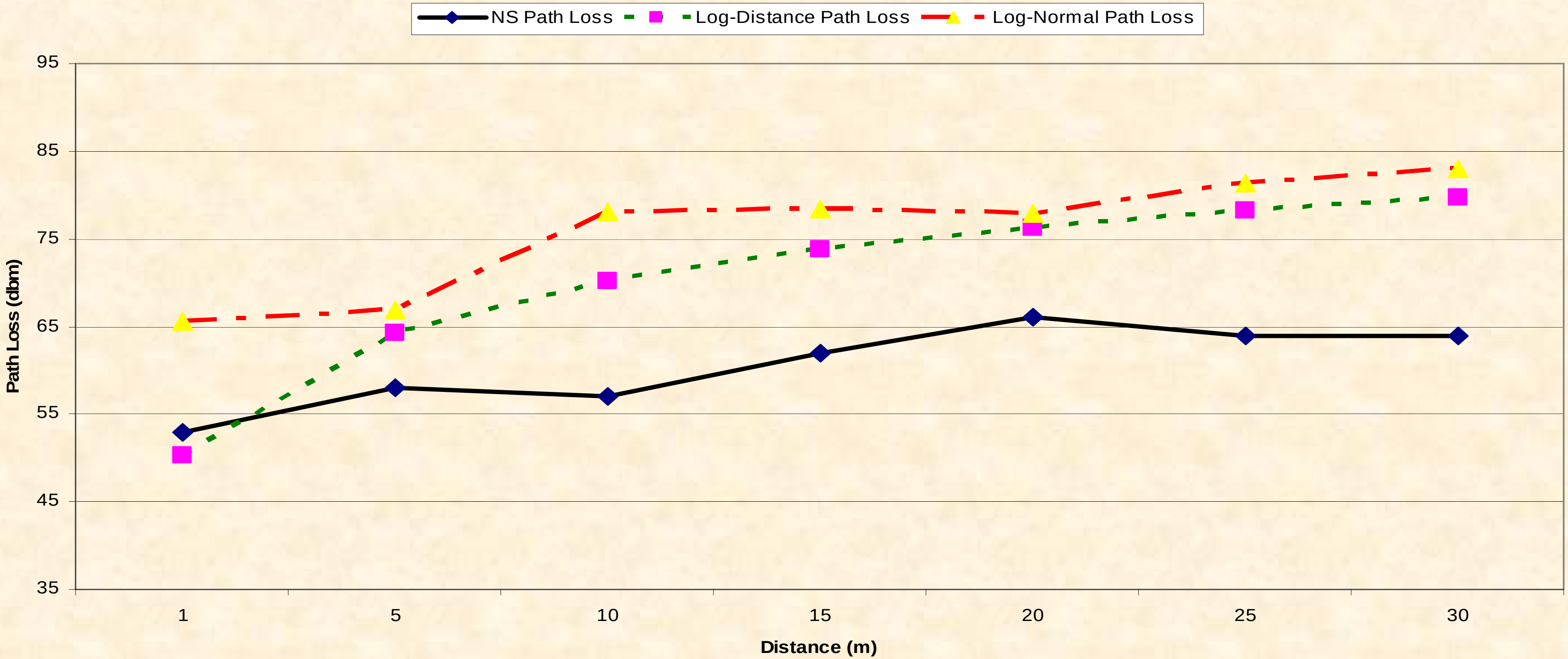


Distance from TX (m)	Direction from AP	NS RX Signal Dbm	TX dbm	NS Path Loss	Log-Distance AvgPL (dbm) (n=2)	Log-normal Shadowing	X_0
1	South	-26	20	46	50.25	64.542038	14.29204
5	South	-49	20	69	64.2294	72.747612	8.518212
10	South	-43	20	63	70.25	53.954549	-16.2955
15	South	-52	20	72	73.77183	91.217525	17.4457
20	South	-51	20	71	76.2706	76.736239	0.465639
25	South	-51	20	71	78.2088	71.372055	-6.83674
30.692	South	-65	20	85	79.9905	70.839519	-9.15099

Nestumbler Measured Path Loss vs. Empirical Path Loss Models

Nestumbler Measured Path Loss vs. Empirical Path Loss Models

North of Transmitter



Distance from TX (m)	Direction from AP	NS RX Signal Dbm	TX dbm	NS Path Loss	Log-Distance AvgPL (dbm) (n=2)	Log-normal Shadowing	X_0
1	North	-33	20	53	50.25	65.617913	15.36791
5	North	-38	20	58	64.2294	66.938046	2.708646
10	North	-37	20	57	70.25	78.127206	7.877206
15	North	-42	20	62	73.77183	78.3385	4.566674
20	North	-46	20	66	76.2706	77.943268	1.672668
25	North	-44	20	64	78.2088	81.350926	3.142125
30	North	-44	20	64	79.79243	82.923333	3.130908

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Conclusions

- **Manual wireless network deployments are inefficient**
- **Multi-path and other environmental interference effects force multiple iterations of all wireless network deployment techniques.**
- **Measurements combined with empirical models will increase the efficiency and effectiveness of SensorNet network deployments.**
- **Interference and path-loss detection tools need to improve to better characterize multi-path and RF attenuation effects**
- **A wireless sensor network environmentally configurable test bed would provide great exercise for this simulator.**

Summary

- Considered a manual deployment of a wireless networks in infrastructure mode
  - Infrastructure-mode coverage of sensor networks
  - Incorporated COTS Tools and Technologies
- Developed Wireless Network Deployment Process
  - All wireless network deployments are an iterative process
  - Measured Signal Strength with available COTS tools
  - Matching RF theory and practice will greatly assist with the choice of an appropriate empirical model to make wireless networks more effective
- Future Work
  - Develop and implement an automated wireless deployment tool
  - Explore more RF path-loss models to better characterize <u>any</u> environment

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Questions?