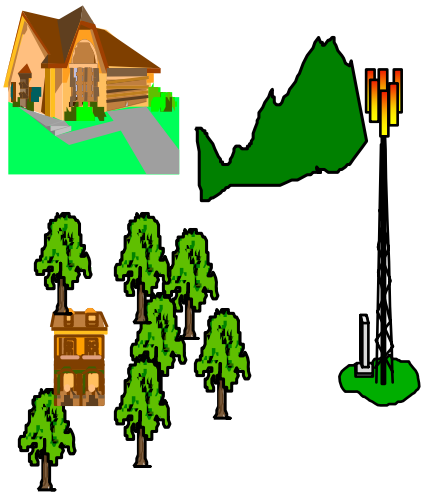
Creating Wireless Multi-hop Topologies on Space-Constrained Indoor Testbeds Through Noise Injection

WINLAB IAB, 15th Nov 2006

Sanjit Kaul
Marco Gruteser
Ivan Seskar
{sanjit, gruteser, seskar}@winlab.rutgers.edu

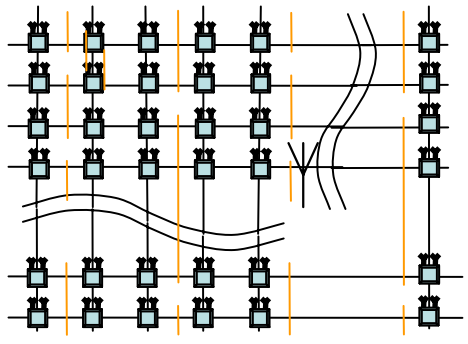
Broad Challenge

Suburban



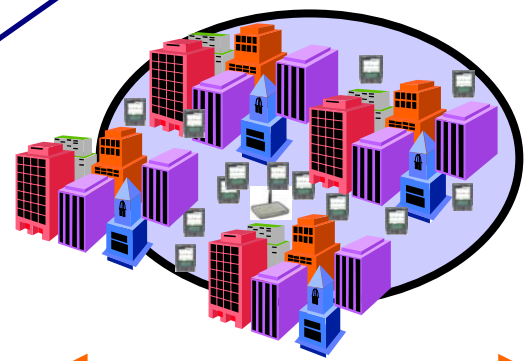
500 meters

ORBIT Testbed



20 meters

Urban



300 meters

Office

30 meters

Hallway

20 meters

WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

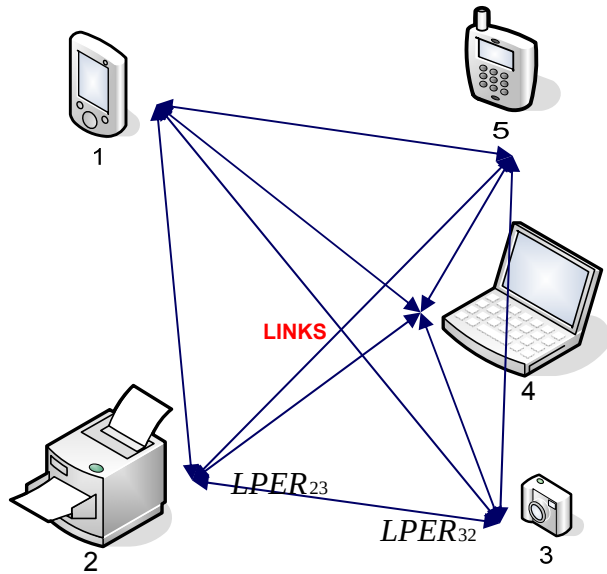
Scope Of Work

- **Map *Wi-Fi network topologies* on ORBIT (The Radio Mapping Problem)**
- **Challenge**
  - **Create them *without any specific configuration of the Wi-Fi stack*.**

The Radio Mapping Problem

Radio Mapping – Choosing a Metric

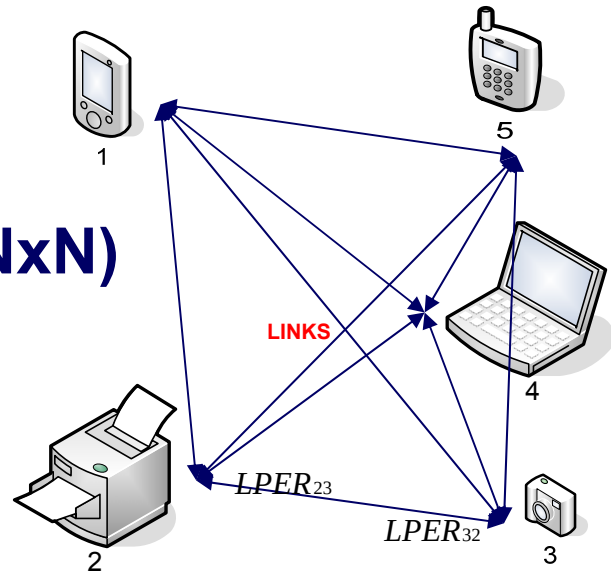
- Map Links in a network
- Choosing a Link Metric
  - Common Metrics
    - Link Packet Error Rate (LPER)
    - Signal to Noise Ratio (SNR)
  - We choose LPER *(doesn't include PER due to collisions)*



Radio Mapping – Defining a virtual scenario

- **Define a virtual scenario**
  - **N nodes**
  - **Time invariant Link PER Matrix (NxN)**

	1	2	3	4	5
1	-	$LPER_{12}$	$LPER_{13}$	$LPER_{14}$	$LPER_{15}$
2	$LPER_{21}$	-	$LPER_{23}$	$LPER_{24}$	$LPER_{25}$
3	$LPER_{31}$	$LPER_{32}$	-	$LPER_{34}$	$LPER_{35}$
4	$LPER_{41}$	$LPER_{42}$	$LPER_{43}$	-	$LPER_{45}$
5	$LPER_{51}$	$LPER_{52}$	$LPER_{53}$	$LPER_{54}$	-

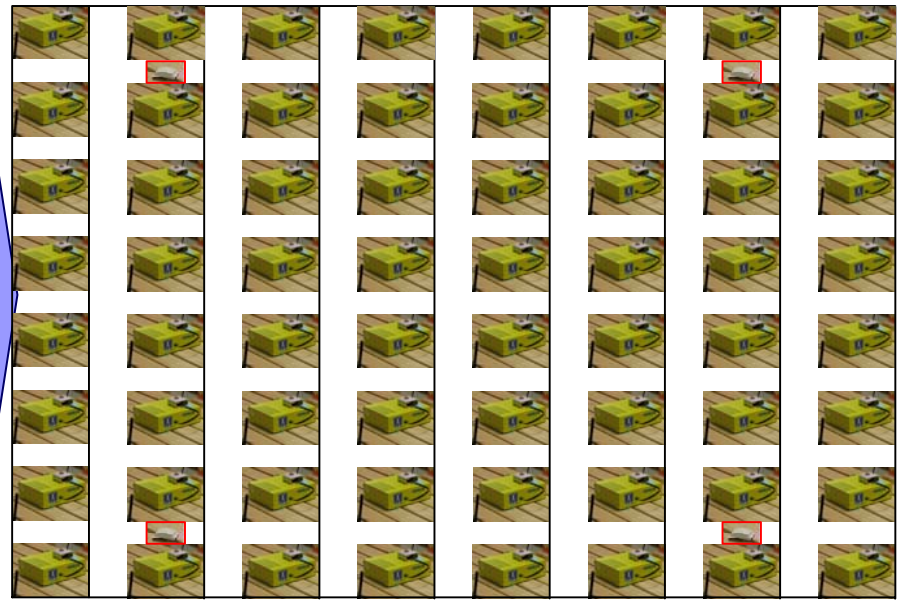


The **desired** LPER matrix

$LPER_{ij}$ is the LPER seen at i when only j transmits.

Mapping the LPER matrix on ORBIT

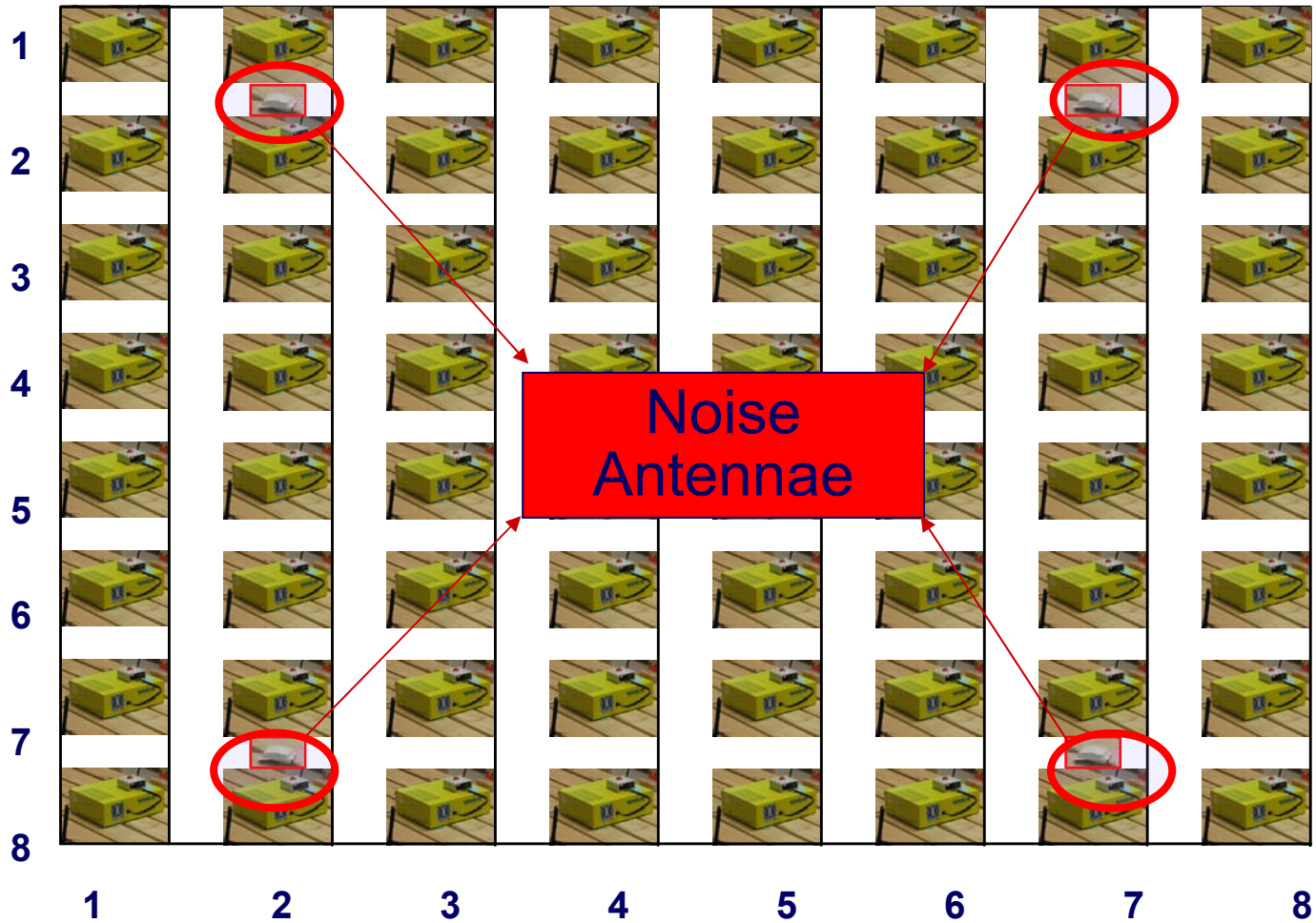
	1	2	3	4	5
1	-	$LPER_{12}$	$LPER_{13}$	$LPER_{14}$	$LPER_{15}$
2	$LPER_{21}$	-	$LPER_{23}$	$LPER_{24}$	$LPER_{25}$
3	$LPER_{31}$	$LPER_{32}$	-	$LPER_{34}$	$LPER_{35}$
4	$LPER_{41}$	$LPER_{42}$	$LPER_{43}$	-	$LPER_{45}$
5	$LPER_{51}$	$LPER_{52}$	$LPER_{53}$	$LPER_{54}$	-



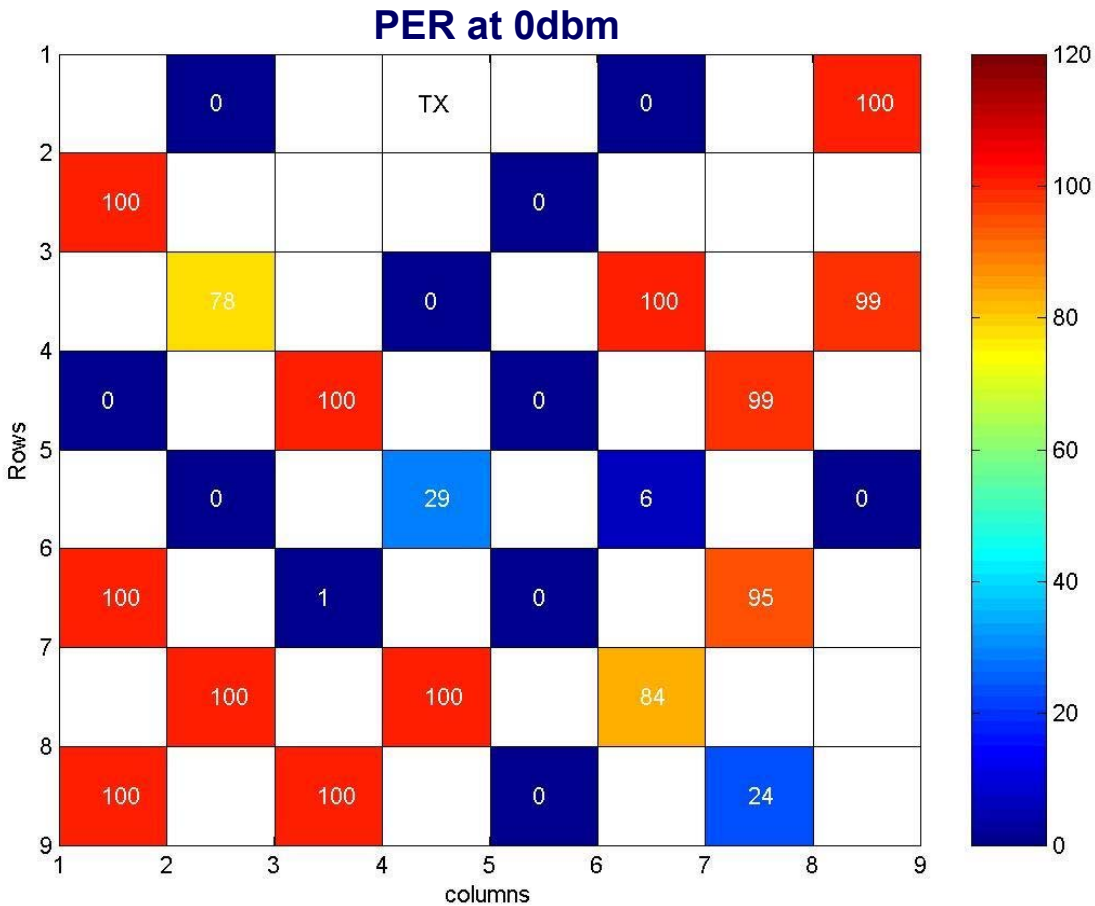
- **Finding five nodes on the ORBIT grid that have the same LPER matrix as the *desired* LPER matrix.**
- **The ORBIT grid LPER matrix is a zero matrix!**
- **How do we map? – *Introduce Packet errors by injecting noise***

WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

Introducing PER by injecting Noise



PER at Grid Nodes at 0dbm, TX is (1,4)



Effect of Noise On Cards

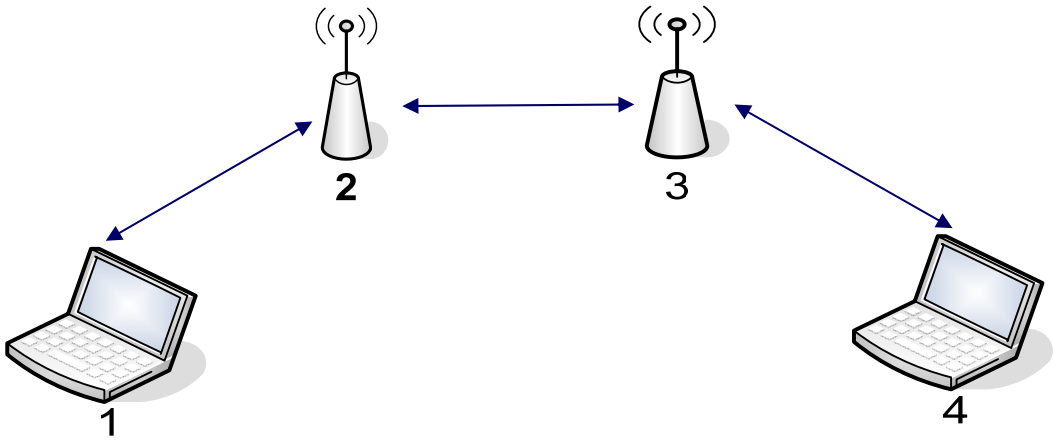
- Atheros calibrates every 30 seconds by default
- Considers the noise introduced to be an increase in ambient noise, the noise floor.
  - As a result the card's carrier sense doesn't disallow transmissions.

Radio Mapping Algorithms

The **Fix Nodes** *Approach*

- **Assumes that propagation is characterized by a certain path loss exponent.**
  - ***Select nodes on grid such that the relative distances between the grid nodes is same as that in the actual real world scenario.***
  - ***Links are symmetric***
  - ***Links have either 0% or 100% PER.***
- **Assumes that interference can be set at each grid node independently of the other.**
- **Adjust interference at each node to satisfy the desired LPER matrix.**

Fixed Node Approach – Three Hop Topology



Desired LPER matrix

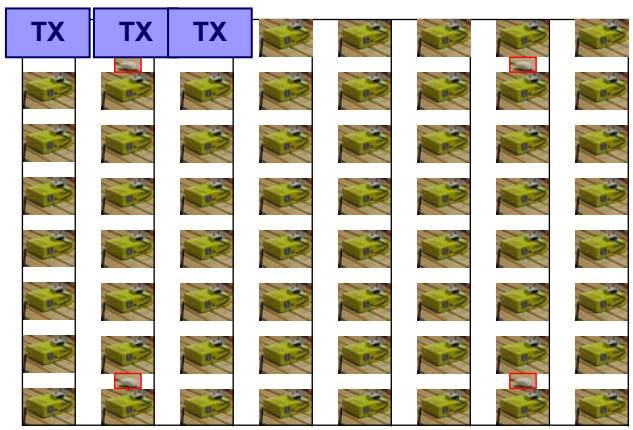
	1	2	3	4
1	-	0%	100%	100%
2	0%	-	0%	100%
3	100%	0%	-	0%
4	100%	100%	0%	100%

1-1	TX	1-3	0	1-5	100	1-7	100
1-1	0	1-3	TX	1-5	1	1-7	100
1-1	100	1-3	0	1-5	TX	1-7	0
1-1	98	1-3	100	1-5	0	1-7	TX

At -20dbm at each antenna

The **Fixed Interferer** *Approach*

- **Fixed Interferers, Much lesser than number of nodes on the testbed.**
- **Methodology**
  - **Search for desired LPER matrix through the Grid LPER profiles at *different* interference levels.**



Grid LPER profiling

- **Select interference levels, say {-15, -10, -5, 0}dbm.**
- **At Each interference level measure the LPER matrix for all Grid Nodes.**

-	$LPER_{12}$	$LPER_{13}$
$LPER_{21}$	-	$LPER_{23}$
$LPER_{31}$	$LPER_{32}$	-

One Matrix for an Interference Level

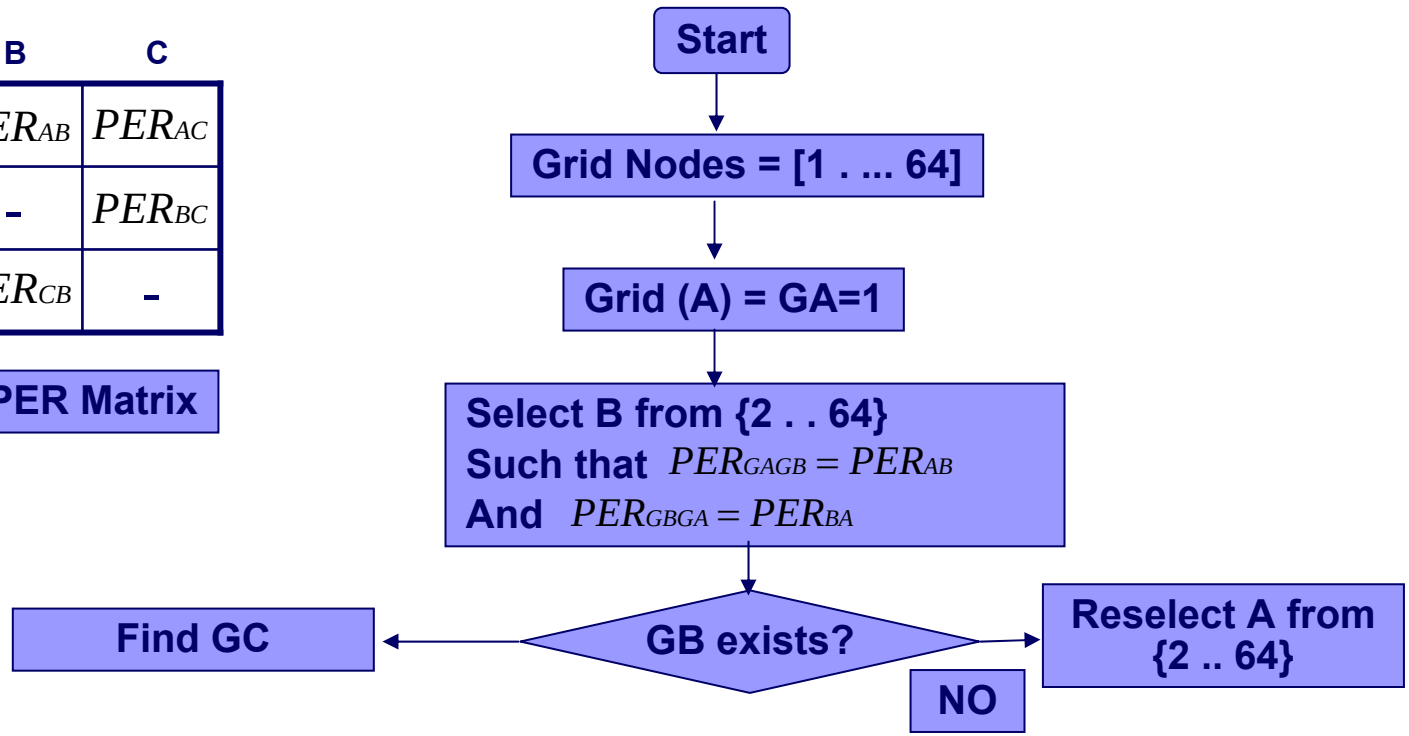
WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

Fixed Interferer *Approach contd..*

- **Backtracking Approach**

	A	B	C
A	-	PER_{AB}	PER_{AC}
B	PER_{BA}	-	PER_{BC}
C	PER_{CA}	PER_{CB}	-

Desired PER Matrix



Fixed Interferer *Approach contd..*

- **If mapping is not found:**
  - **Restart search with increased per error tolerance.**

	A	B	C
A	-	PER_{AB}	PER_{AC}
B	PER_{BA}	-	PER_{BC}
C	PER_{CA}	PER_{CB}	-

Desired PER Matrix

Desired PER Matrix - Δ * I ≤
Desired PER Matrix ≤ Desired PER Matrix + Δ * I
Where Δ is the error tolerance.

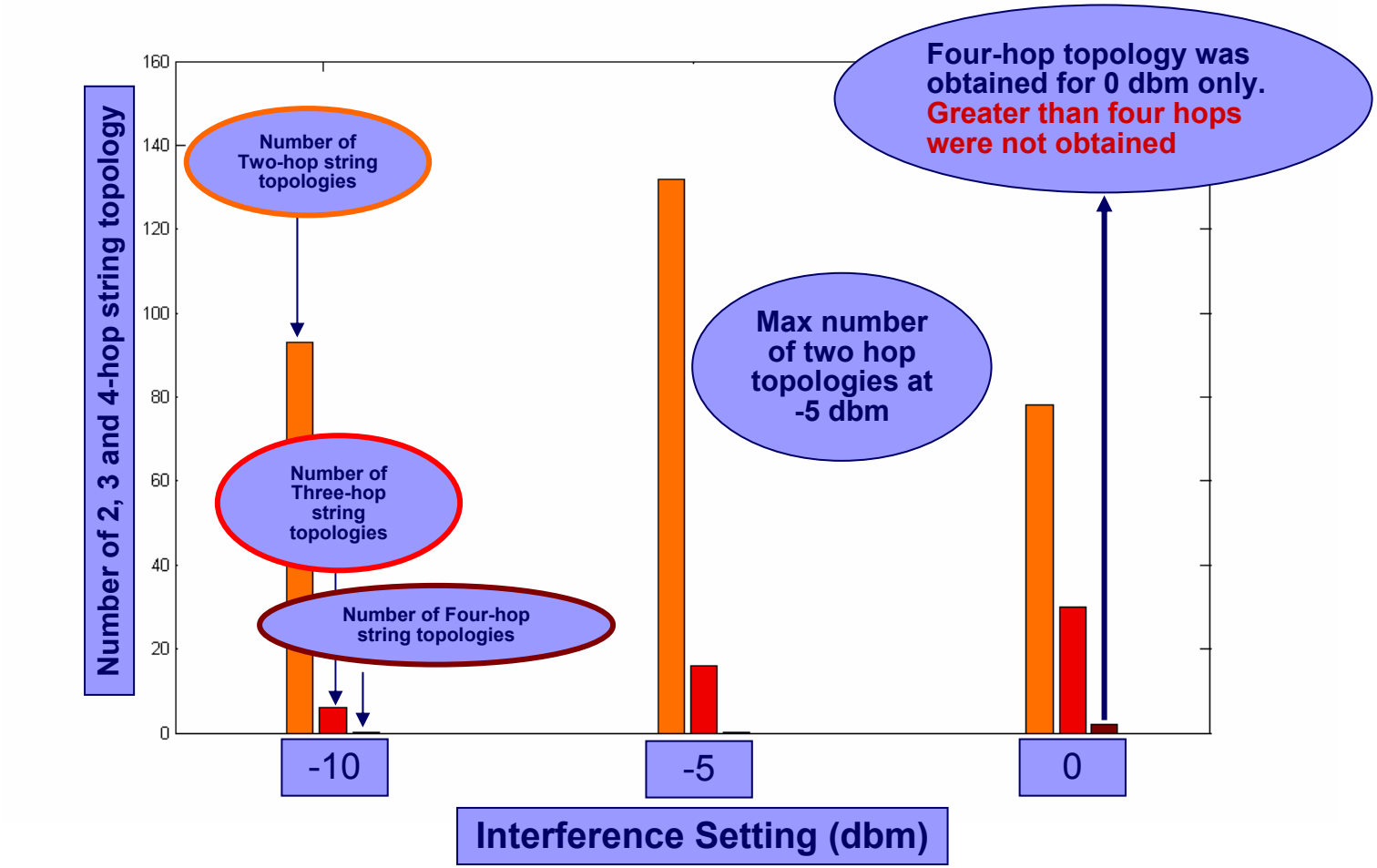
String Topologies obtained using Fixed Interferer approach

- Measure Grid PER Profile at -10, -5 and 0dbm interference setting.
- Find the number of node pairs for each profile that:
  - Are connected via *at least*
    - 2 hops (2 other nodes on the grid)
    - 3 hops
    - 4 hops

	A	B	C
A	-	0%	100%
B	0%	-	0%
C	100%	0%	-

Desired Link PER matrix (2 hops)

String Topologies obtained using Fixed Interferer approach



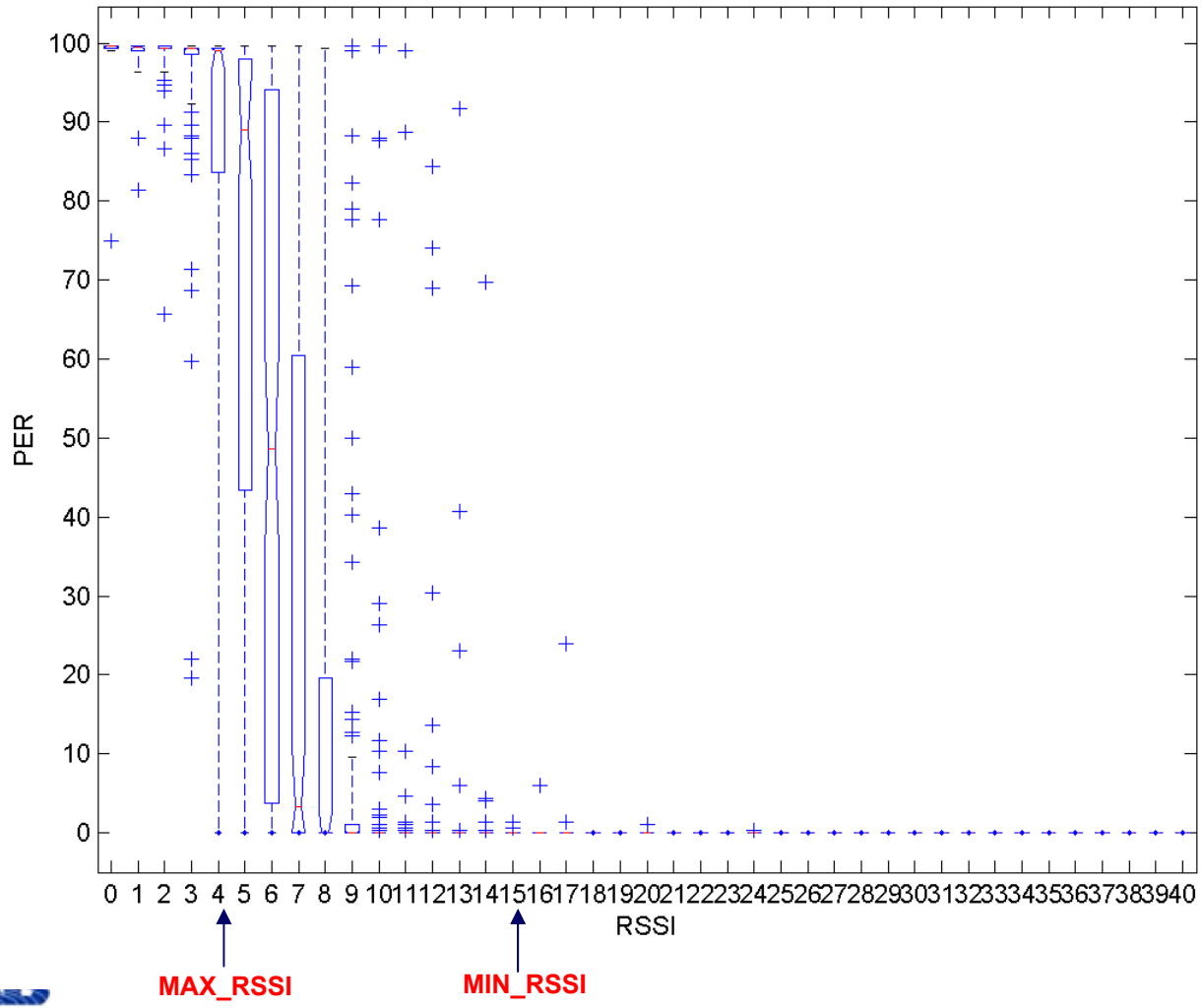
64 Node ORBIT Grid, 32 Atheros nodes were used.
Every other node on the grid was Atheros.

Fixed Interferer & Fix Nodes

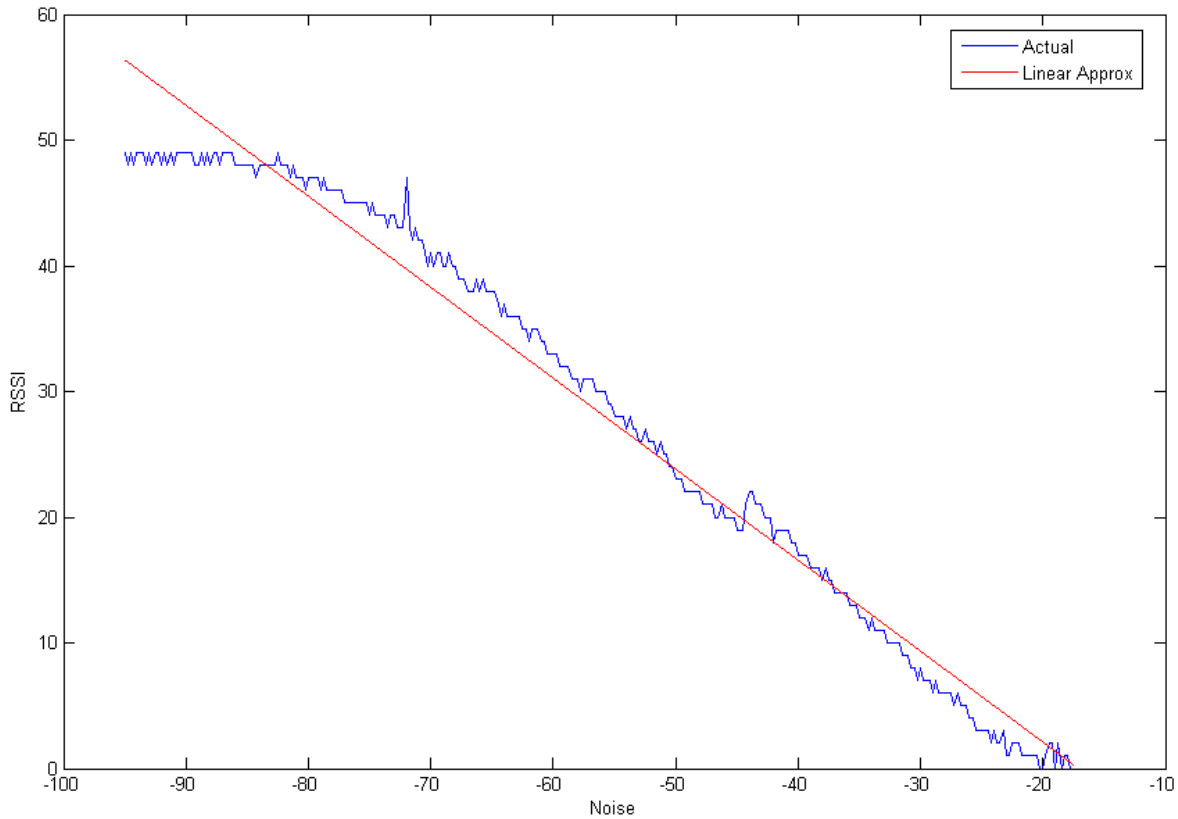
- **Fixed Interferer** approach has a very high time complexity.
- It is a brute force search that will find a mapping if it exists.
- **Fix Nodes** approach is not feasible if number of noise antennae are lesser than the number of nodes in the topology.

- We desire an approach that -
  - Minimizes complexity
  - Uses Minimum a priori measurements
  - Finds a topology if it exists
  - Scales well to include links with different PHY rate and packet size.
- How?
  - Fixed Interferer searches PER profiles.
  - Look at relation between PER and RSSI, RSSI and Noise.

RSSI PER Correlation



RSSI vs. Noise



RSSI = -0.7238 * Noise -12.4068

Coarse Mapping

Quantize the LPER Matrix

- Up Link (LPER<=15%)
- Down Link (LPER>15%)

	I	II	III
I	-	5%	80%
II	10%	-	10%
III	95%	7%	-

Desired LPER Matrix

-	0%	100%
0%	-	0%
100%	0%	-

Quantized LPER Matrix

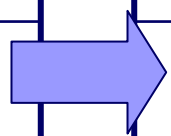
Coarse Mapping

Map Quantized Matrix to an RSSI Matrix

- Two-Valued (MAX_RSSI = 4, MIN_RSSI = 15)

-	0%	100%
0%	-	0%
100%	0%	-

Quantized LPER Matrix



-	≥ 15	≤4
≥15	-	≥ 15
≤ 4	≥ 15	-

Corresponding RSSI Matrix

WINLAB
WIRELESS INFORMATION NETWORK LABORATORY

Coarse Mapping

- Get RSSI profile at No Noise
- Let's assume that the grid has only three nodes

Example Grid RSSI Profile

I	-	60	40
II	60	-	60
III	40	60	-
	I	II	III

Coarse Mapping

Grid RSSI profile

-	60	40
60	-	60
40	60	-

—

RSSI Matrix to be mapped

-	≥15	≤ 4
>=15	-	≥ 15
≤ 4	≥ 15	-

=

Change in RSSI Matrix

-	≤ 45	≥ 36
≤ 45	-	≤ 45
≥ 36	≤ 45	-

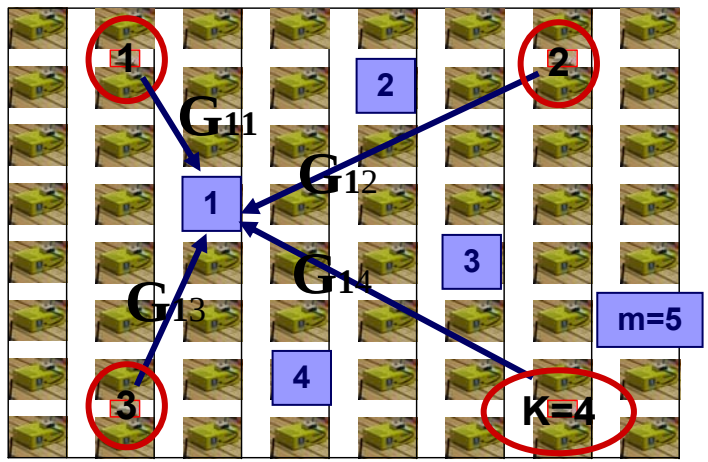
Change in Noise Matrix at each selected Grid Node

36/0.7 (db)	0	36/0.7 (db)

Coarse Mapping

Find noise settings at the fixed antennae that best achieve the noise required at each node (k- noise antennae, m nodes)

$$\begin{bmatrix} G_{11} & G_{12} & G_{1k} \\ G_{21} & G_{22} & G_{2k} \\ & & \\ G_{m1} & G_{m2} & G_{mk} \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \\ \\ n_k \end{bmatrix} = \begin{bmatrix} N_1 \\ N_2 \\ \\ N_m \end{bmatrix}$$



$$[n] >= 0$$

Nonnegative least-squares constraints problem (lsqnonneg)

Fine Tune (Future Work)

- Fine tune the coarse mapping
  - **Vary noise at nodes selected in the coarse mapping to achieve the non-quantized original *desired LPER matrix***

Conclusion

- Introduction of AWGN was used to create multi-hop topologies on ORBIT.
- Two Approaches: Fix Nodes and Fixed Interference were discussed
- An approach with reduced time complexity was also proposed
  - Coarse Mapping, where we map a quantized LPER matrix.

Current Status of the Project

- Mapping 4-hop topologies on the 400 node grid
- Mapping of home network topologies (6 node)

Default Configuration

Interference Type	AWGN
Interference Power	-5dbm
Interference Bandwidth	20Mhz
Interference Center Frequency	2.422Ghz
Channel	3
Mode	802.11g
Transmit Power	20dbm
PHY rate	1Mbps

PER With Gradually Increasing Noise