INTERFERENCE ESTIMATION AND AUTOMATED GENERATION OF SPATIAL REUSE MAP FOR WIRELESS MESH NETWORKS

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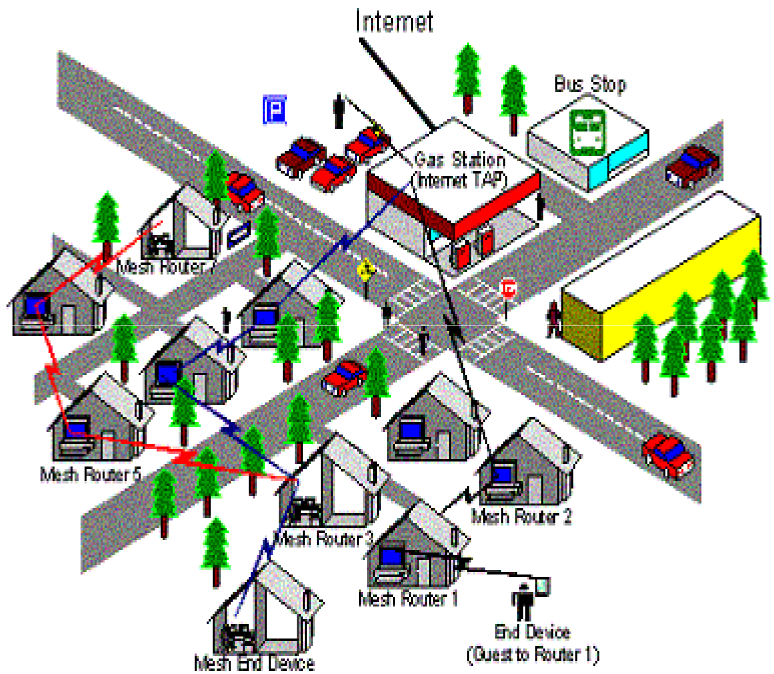
Outline

- Introduction
  - Motivation
  - Problem statement
  - RSSI based prediction
- Interference Estimation
  - Measurements performed
  - SIR based interference estimation
- Time-Period Analysis
  - Measurement duration
  - Measurement interval
- Putting it all together
- Conclusion and Future work

Introduction

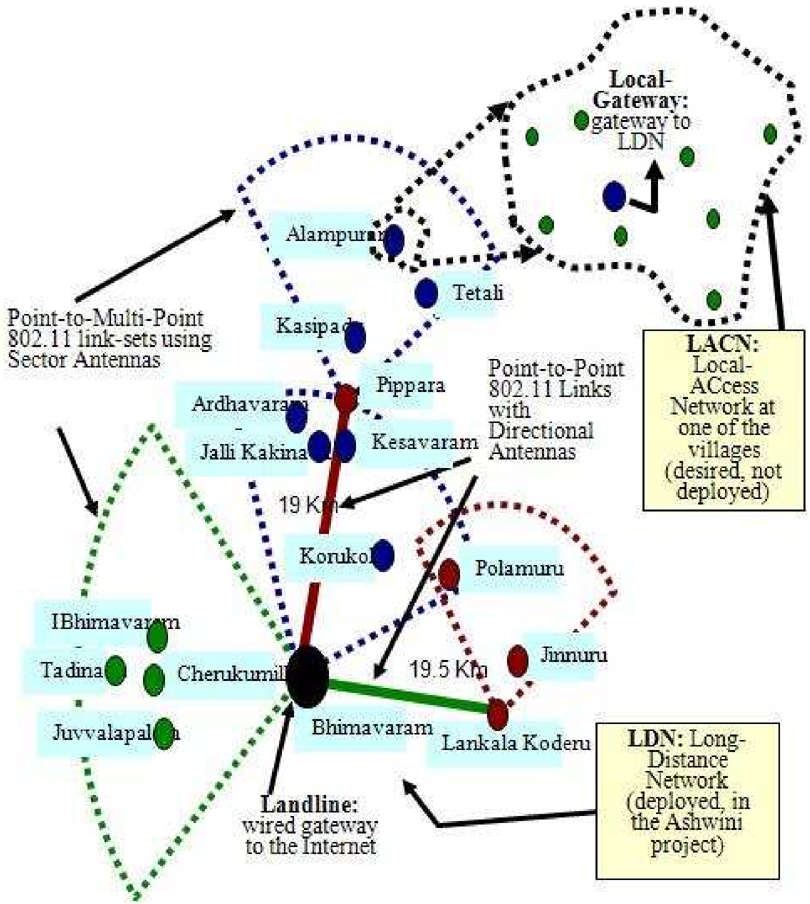
- Wireless Mesh Networks
  - Co-operative set of wireless nodes organized as mesh-clients and mesh-routers to form a communication network
  - Low cost, last-hop internet access networks
- WMN's are
  - **Flexible** => links are unplanned
  - **Scalable** => May vary form small indoor settings to large and long-distance community networks.



Source: http://research.microsoft.com/mesh/

FRACTEL

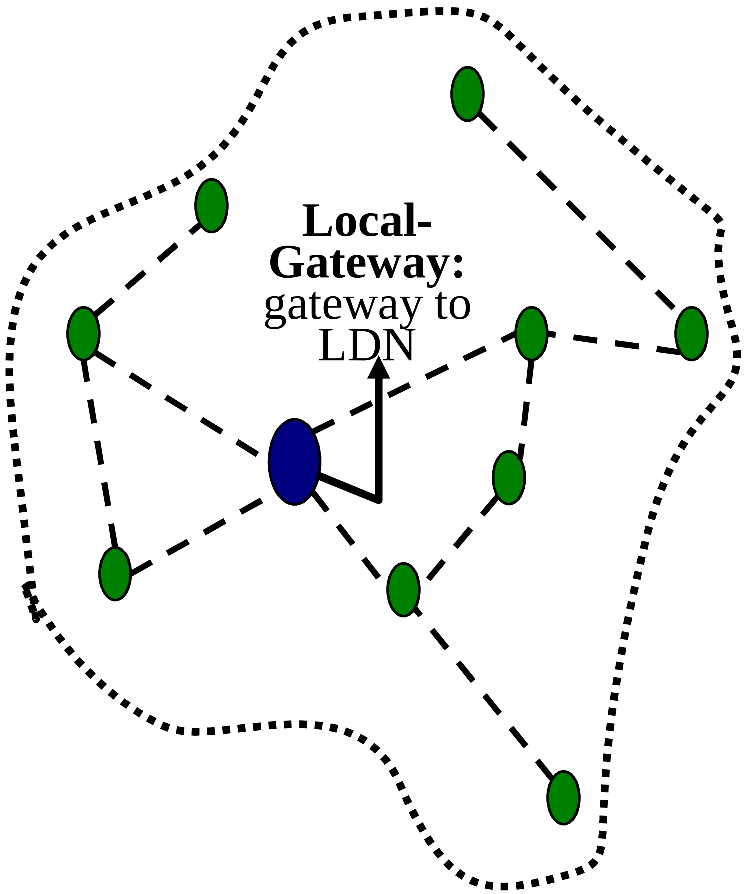
- wi-**F**i based **R**ural **AC**cess **TEL**ephony.
- Low cost : uses off-the-shelf WiFi hardware
- Long Distance Network
  - Connect local-gateways to wired backbone network.
- Local ACcess Networks
  - Connect various nodes in the village to local-gateways to
- TDMA based MAC for provisioning voice and video capabilities



FRACTEL Network [14]

Motivation

- Interference is one of the key factors that influence(degrade) the performance of WMNs
- Interference Map in TDMA-based network
  - Indicates the possibility of spatial re-use.
  - Key input to channel assignment and routing.
- Automated Interference Estimation
  - Helps us establish scalable, flexible and unplanned wireless mesh networks.
  - Allows dynamic changes in the network.



LACN network FRACTEL

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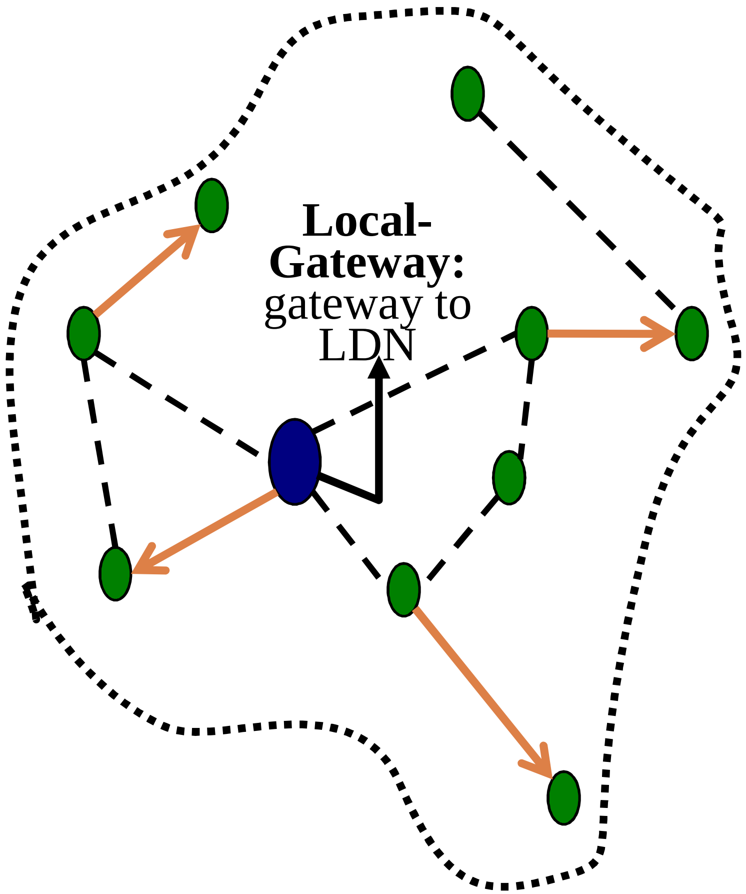


LACN network FRACTEL

Our work : Problem statement

- Study interference characteristics specific to TDMA-based networks, by careful and detailed experimentation
- Formulate an effective strategy for estimating interference based on measurements.
- Develop an automated mechanism to generate the spatial re-use map using regular measurement.
- Envisioned for medium range out-door meshes (LACN).

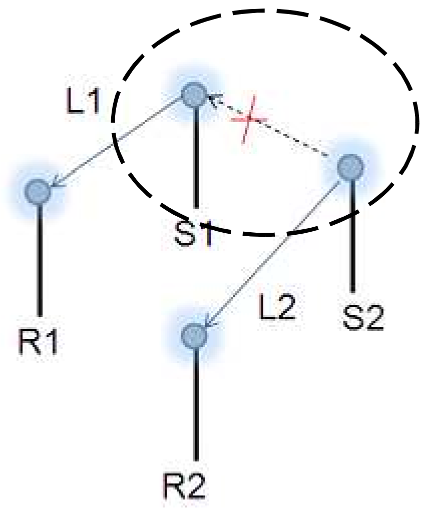
RSSI based Interference Estimation

- **Premise** : There exists strong correlation between the received signal strength at a particular receiver from different senders and the amount of interference that a each of them exerts upon the other.
- ✓ Only **O(N)** measurements required for N-nodes.
- ✓ Interference measurements are **reliable** compared to prediction based methods

Interference @ Sender

- At sender.
  - If signal strength is above the sensitivity of radio, it will back-off while carrier sensing
  - Non-destructive Interference

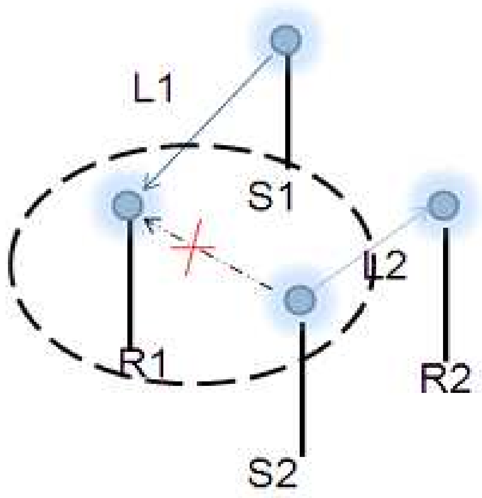
- RSSI received by S2 from S1- $RSSI_{S2}^{S1}$ in Fig1 will determine the amount of carrier sense caused by S1 at S2
- This relation need not be symmetric.



Interference @ Receiver

- At receiver.
  - Depends on the difference between interferer and sender signals strengths- **SIR** (signal to interference ratio)
  - **Capture effect** : If above SIR doesn't exceed by some capture threshold packets are lost due to collision during reception
  - Destructive Interference.

- The difference $RSSI_{R1}^{S1} - RSSI_{R1}^{S2}$ in Figure will determine how much the pair of links L1 and L2 interfere at R1



Background and Related Work

- Multi-way interference
  - Does two or more non interfering links, when acting together cause interference? (Y. Charlie Hu et.al – Characterizing MultiWay Interference In Wireless Mesh Networks)
  - What is the combined effect multiple interferers? (Correlation with distance (Dragosz Niculescu - Interference Map for 802.11 Networks)

Background and Related Work

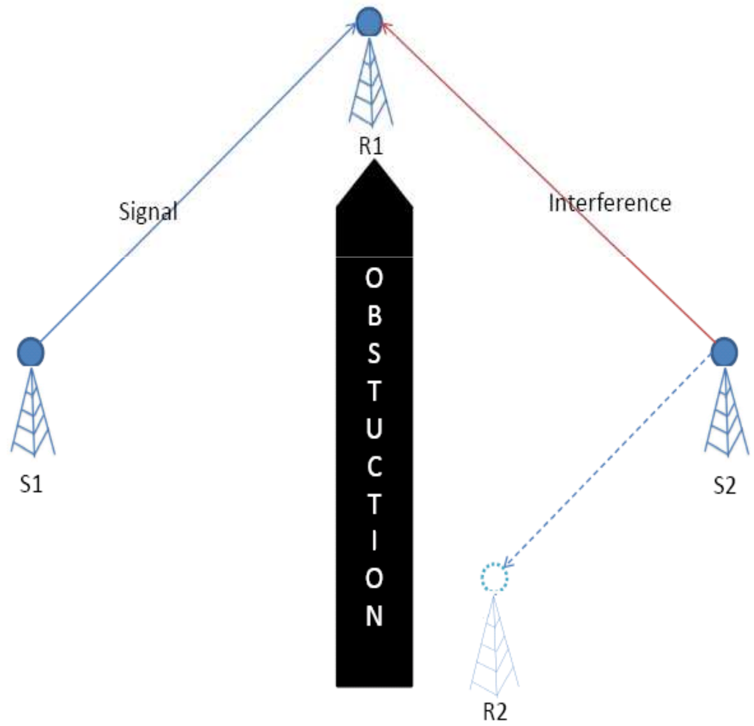
- Pair-wise measurements (Venkata N. Padmanabhan et.al - Estimation of Link Interference in Static Multi-hop Wireless Networks)
  - Pair-wise broadcast
  - $O(N^2)$ complexity
- RSSI based interference estimation
  - O(N) methods
    - Maya Rodrig et.al - Measurement-based models of delivery and interference in static wireless networks.
      - Complex probabilistic modeling of physical layer behavior.
      - Used measured delivery probability, and RSSI to estimate interference.
    - Wonho Kim et.al - RSS-based Carrier Sensing and Interference Estimation in 802.11 Wireless Networks
      - RSSI measurements to predict throughput of the model
      - No- proper evaluation and detail.
  - Both models not specific to TDMA-based networks and out-door networks.

Interference Estimation

1. Measurement Setup and Procedure
2. SNR based prediction model
3. Three way classification using SNR band

Measurements

- AIM: To gauge the relation between interferer signal strength and error rate observed.
- Triplet
  - S1 : Sender
  - S2 : Interferer
  - R1 : Receiver
- No carrier sensing in TDMA –based networks
- hidden-node interferer to generate interference analogous to TDMA networks



Measurement Locations

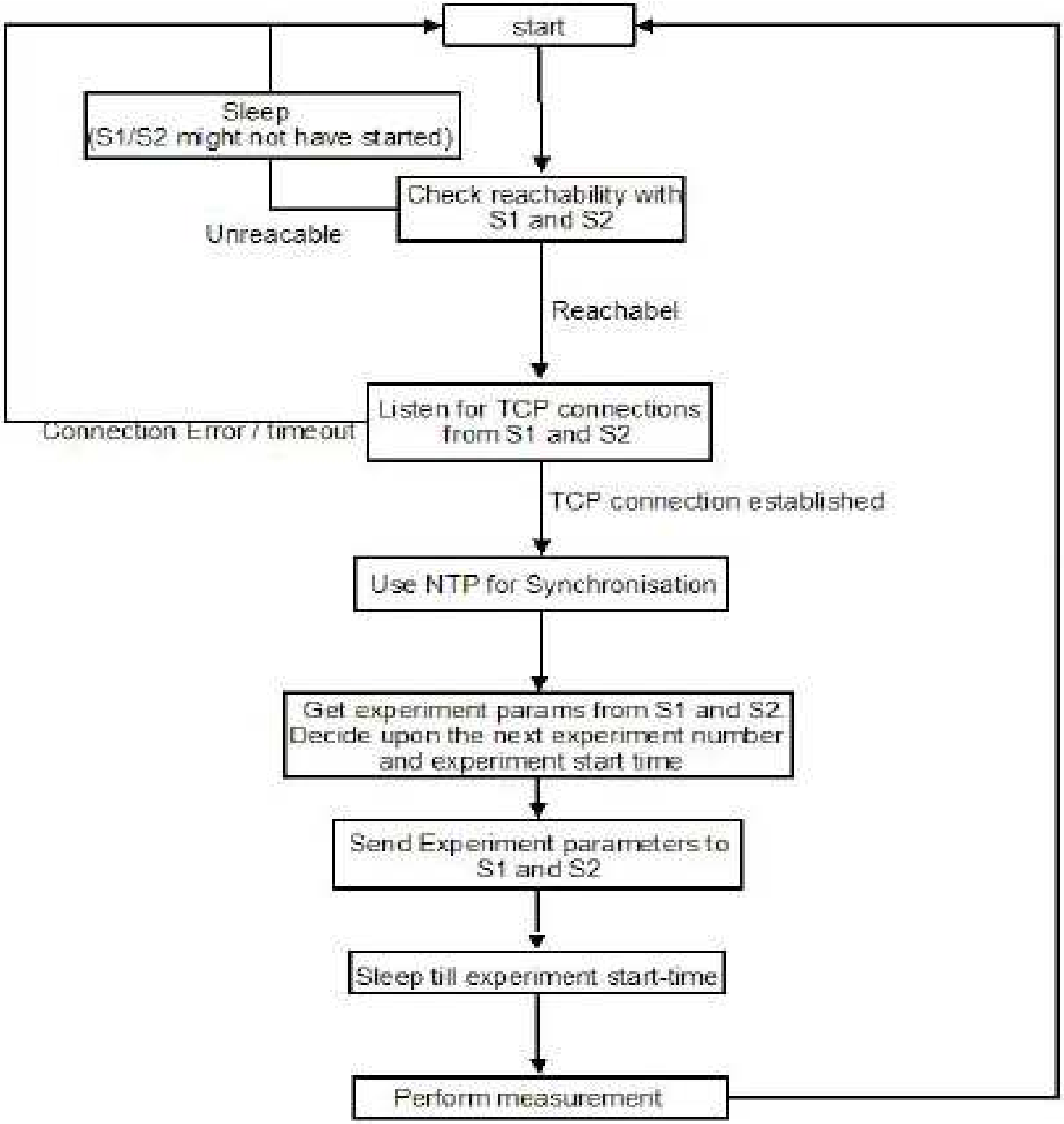
Hostel 12, IITB

Main building - GG building - KReSIT

Courtesy : Google Maps

Measurement Procedure

- At each location, various experiments by varying
  - Transmit rate
  - Sender Tx Power
  - Interferer Tx Power
- S1 acts as central control node to exchange experiment parameters.
- The nodes use NTP for synchronization.


start
Sleep
(S1/S2 might not have started)
Check reachability with
S1 and S2
Unreacable
Reachabel
Listen for TCP connections
from S1 and S2
Connection Error / timeout
TCP connection established
Use NTP for Synchronisation
Get experiment params from S1 and S2
Decide upon the next experiment number
and experiment start time
Send Experiment parameters to
S1 and S2
Sleep till experiment start-time
Perform measurement

Measurement Procedure

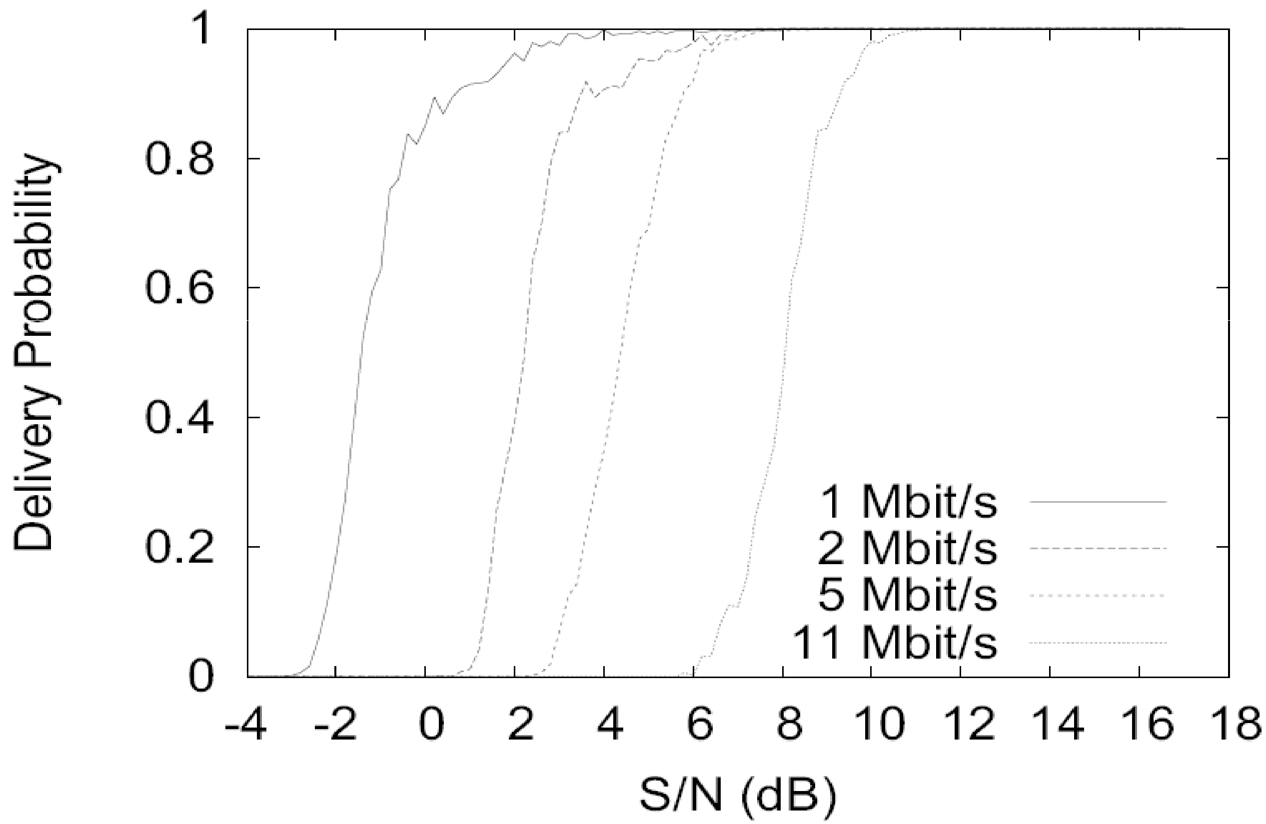
- Simultaneous broadcasts: S1 and S2, broadcast at the same time
  - 1000 byte UDP packets
  - Back to back
  - 30 seconds
  - We measure the delivery probability of S1, in presence of interference from S2
- Individual broadcasts : Individual S1 transmission followed by
  - 1000 byte UDP packets, back-to-back, for 30 seconds
  - We measure the RSSI values at S1 and S2.

SIR based prediction

Signal to Interference Ratio

- SINR is the ratio of the signal strength of the wanted signal to that of the background signal from other links and noise
- Our interference is continuous and very high compared to noise, hence noise factor in SINR is ignored
- SIR v/s Delivery Probability curve
  - Sharp transition from very less (10%) to very high (90%) delivery probability.
- Signal to Interference Ratio
  - As RSSI varies so does SNR

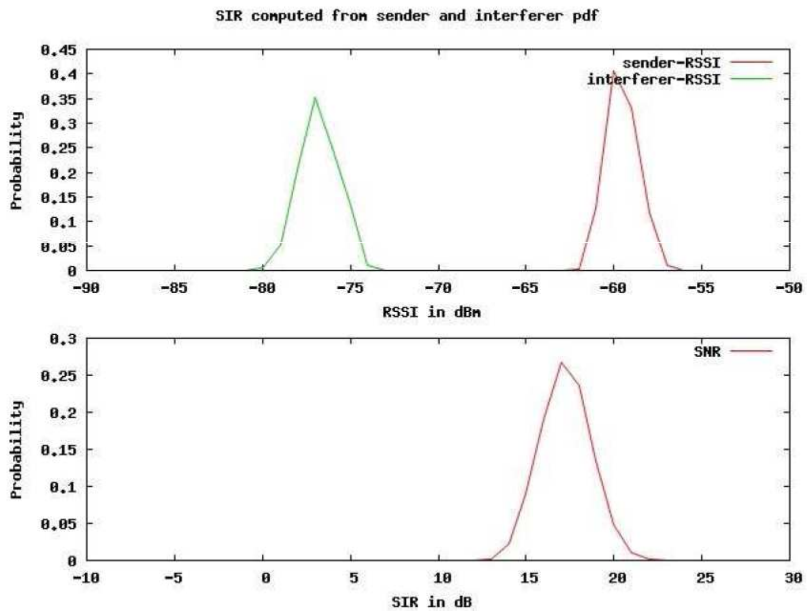
Signal to Interference Ratio



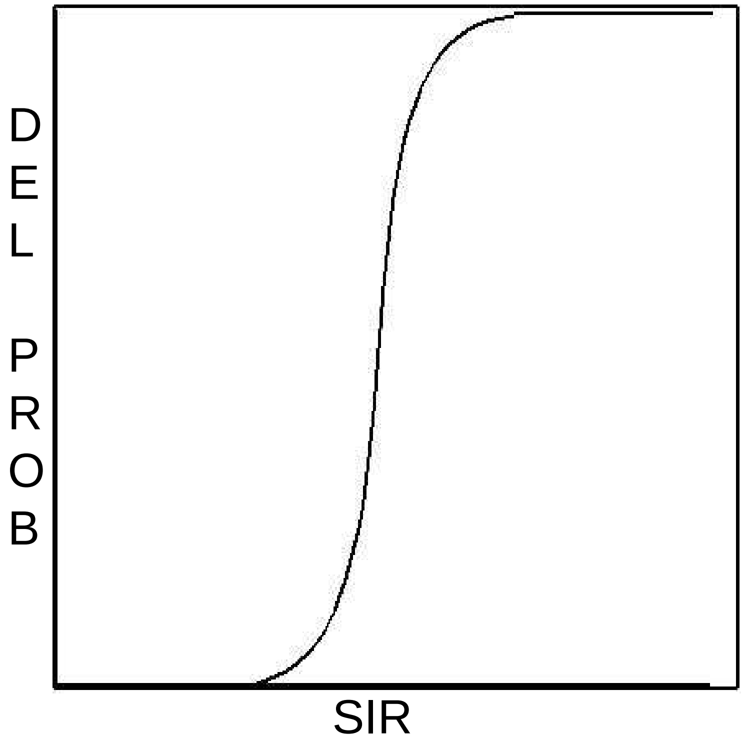
SINR versus Delivery Probability measured during an emulator experiment. Source:Roofnet measurement study

Signal to Interference Ratio

- RSSI can be approximated with a discrete PDF
- Can be calculated from individual sender and interferer approximated RSSI distributions using discrete convolution
- $P_{SIR}(\alpha) = \sum P_x(k) * P_y(k- \alpha)$



Estimation of Delivery Probability



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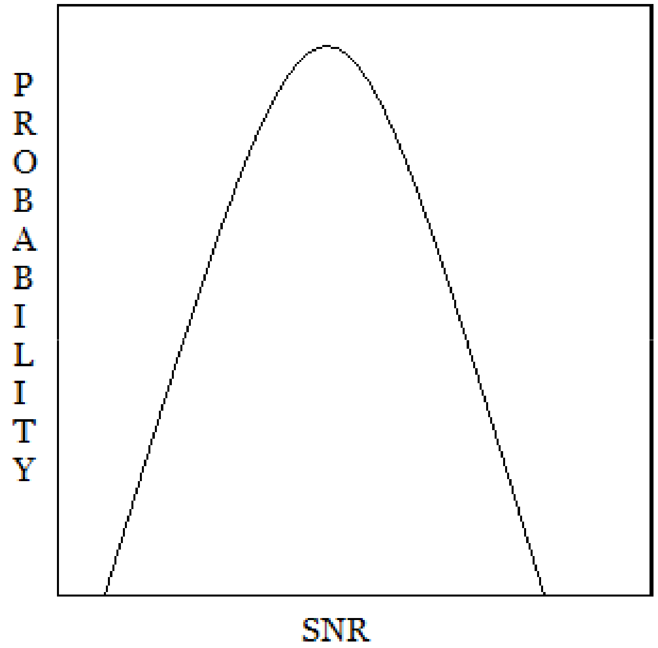
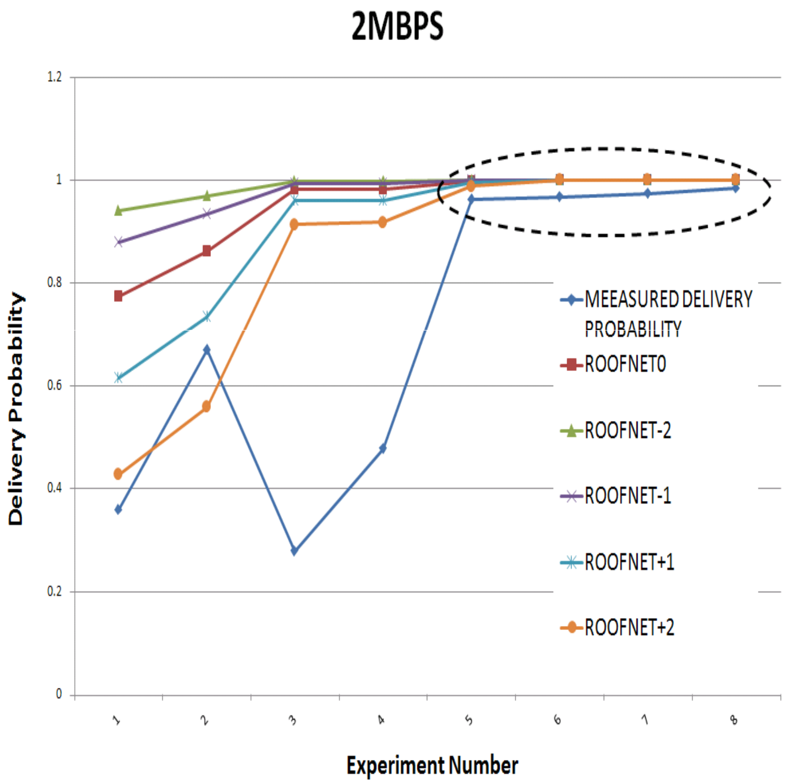


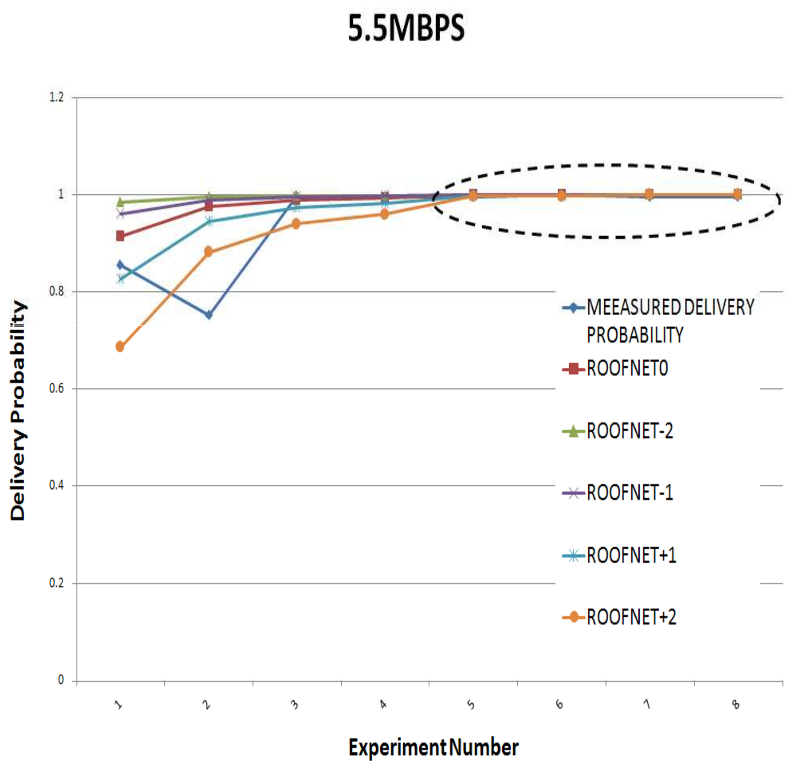
$$DeliveryProbability = \sum P_{SIR}(\alpha) * DP(\alpha)$$

- Since we use different hardware, from roofnet. Along with the actual SIR v/s DP curve, we take curves shifted to the right and left of actual curves. We call them roofnet+1 roofnet+2, roofnet-1 and roofnet-2 and roofnet.

Results



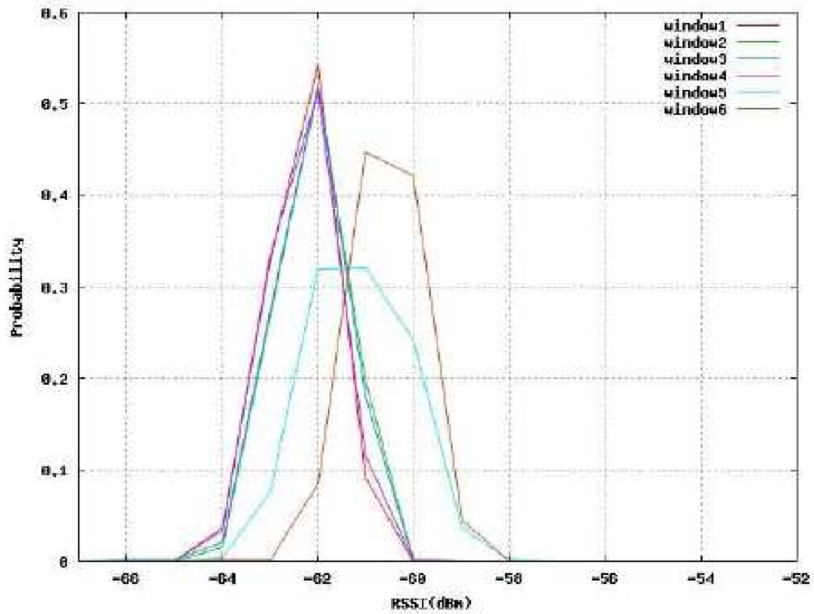
2MBPS
Delivery Probability
Experiment Number
MEEASURED DELIVERY PROBABILITY
ROOFNET0
ROOFNET-2
ROOFNET-1
ROOFNET+1
ROOFNET+2



5.5MBPS
Delivery Probability
Experiment Number
MEEASURED DELIVERY PROBABILITY
ROOFNET0
ROOFNET-2
ROOFNET-1
ROOFNET+1
ROOFNET+2

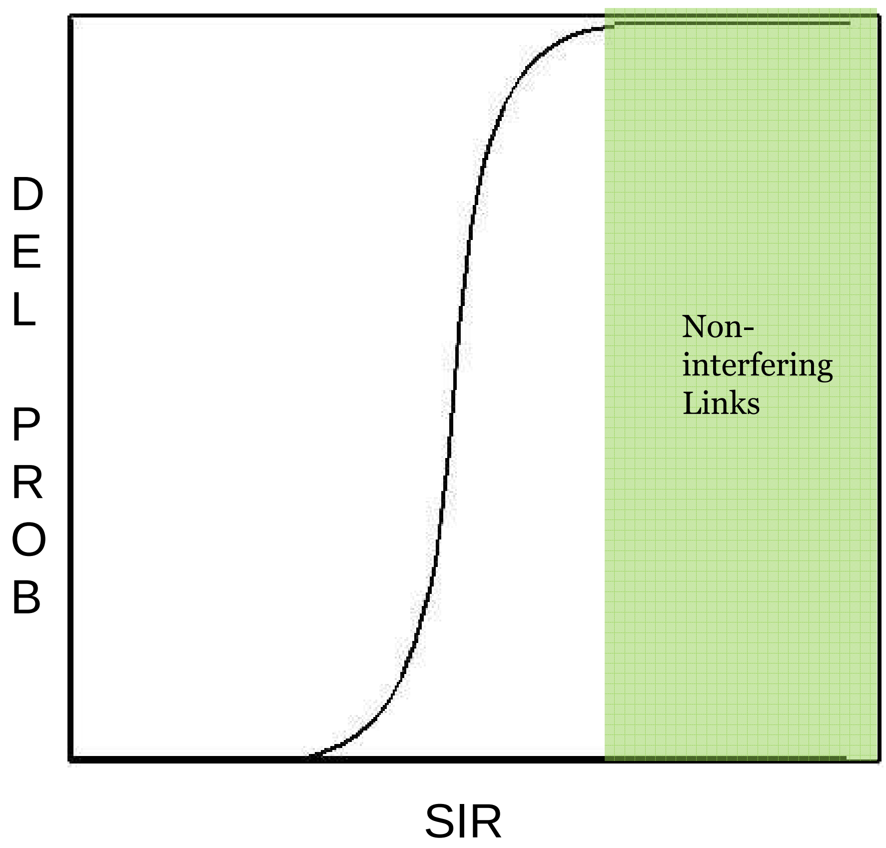
Why?

- How variable is the RSSI?
  - Divide each 30 second experiment into small windows of five seconds
  - Difference in the area under the PDF curve is high
  - The band remains stable
- Due to the variability, accurate prediction of RSSI is not possible

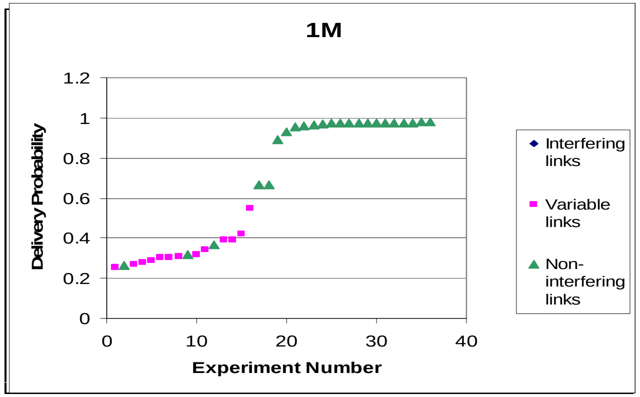


Three-way classification using SIR band

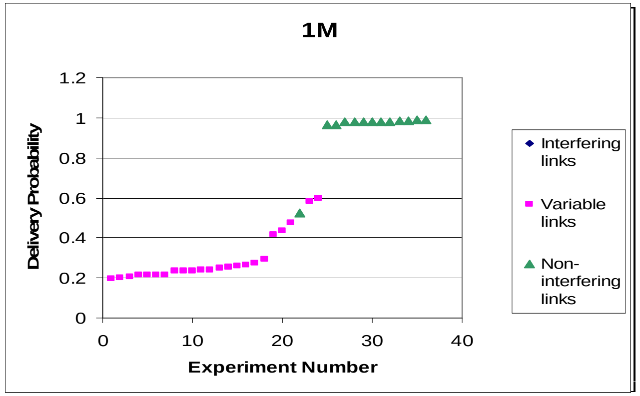
- Use 2.5th to 97.5th percentile band.
- If SIR band lies
  - completely outside the steep region, link delivery probability would be stable and can be predicted.
  - intersects with the steep region, it is impossible to gauge the DP.
- Three way classification
  - Non-interfering Links
  - Interfering Links
  - Intermediate / variable links



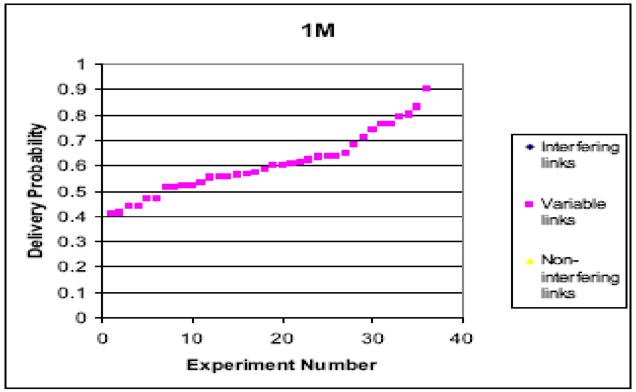
Results 1 Mbps



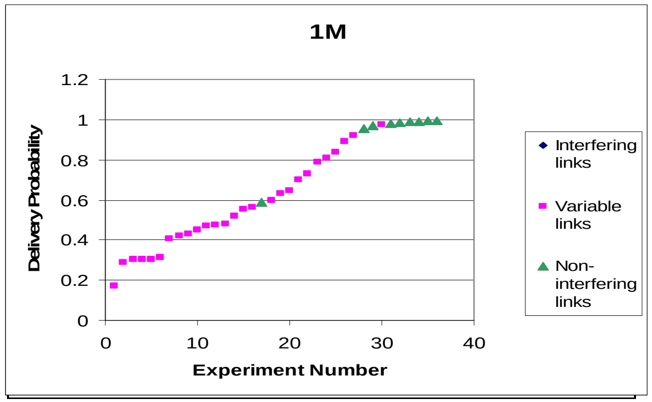
(a) Location1 (type 1)



(b) Location1 (Type 2)



(c) Location2 (type 3)



(d) Location2 (type 4)

RATE	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
ACCURACY	94.8%	90.7%	87.2%	84.6%

Classification: conclusions

- The accurate prediction of delivery probability based on the approximated SIR is not possible. Because of the completely random variability in the link RSSI.
- The inaccuracy is more for the cases with intermediate delivery probability.
- It is possible to classify the link-pairs into one of three categories: interfering, non interfering and variable links, based on SIR band and the SIR versus delivery probability curve.

Time-Period analysis

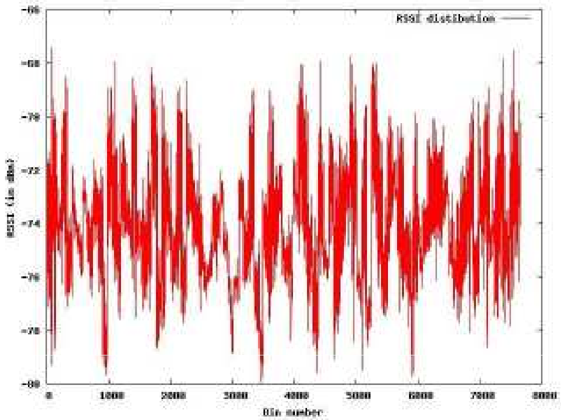
1. Spectral analysis
2. T – measurement interval
3. t – measurement duration

Time period analysis

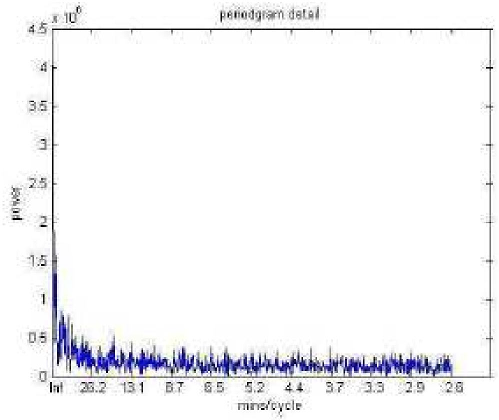
- Two important aspects of automation
  - What should be the time-period (T) (interval between two successive measurements) of measurements, such that the error during the prediction is minimized?
  - What should be the duration (t) of each measurement, such that we collect enough information to predict the RSSI pattern for next T time?
- Analyze long-duration RSSI data from FRACTEL measurement work.

Spectral Analysis

- Use discrete Fourier transforms
  - Convert time domain to frequency domain
  - Prominent frequencies will have peaks in periodogram.
- Auto-correlation
  - Measures the correlation of time-series with itself.
  - No significant pattern found.



(a) RSSI variability (Average RSSI per 1000 packet bin)

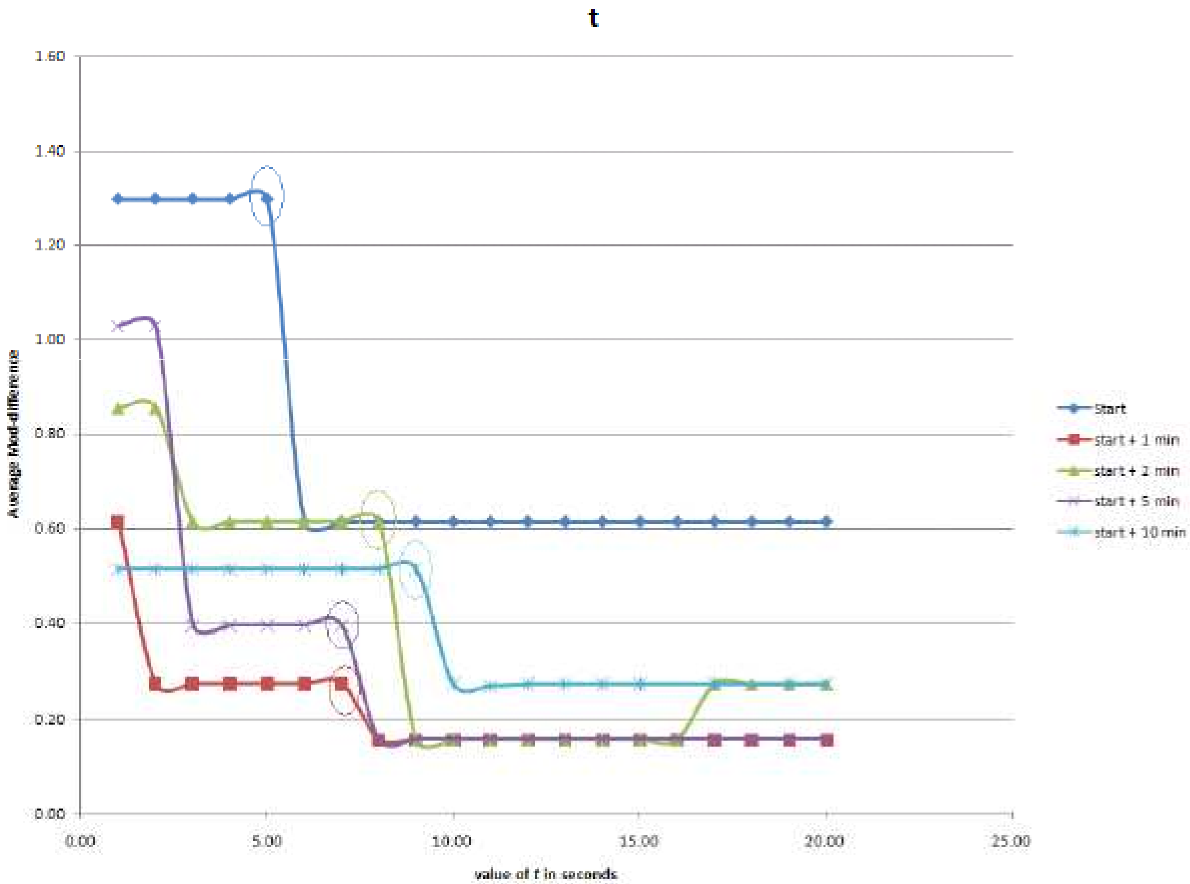


(b) Periodogram detail

Measurement duration *(t)*

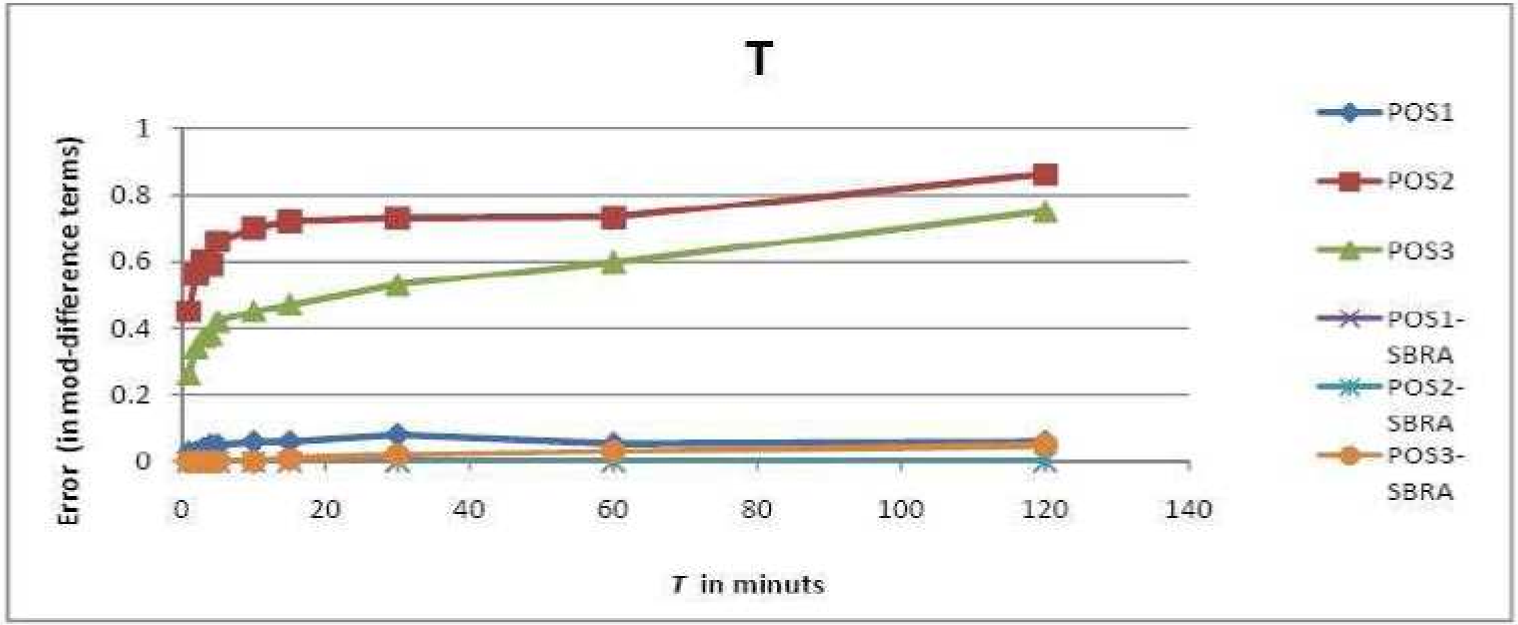
- Take different values of *'t'* and determine the error each of them.
- Divide the time series data into 10 second windows.
- Calculate average error between first 't' seconds and every 10 second window
  - The measured window should cover the variability in the link
  - $Error = max(x_i - x_j, 0) + max(y_j - y_i, 0)$
  - Where $<x_i, y_i>$ & $<x_j, y_j>$ are the 2.5^{th} and 97.5^{th} percentile bands.

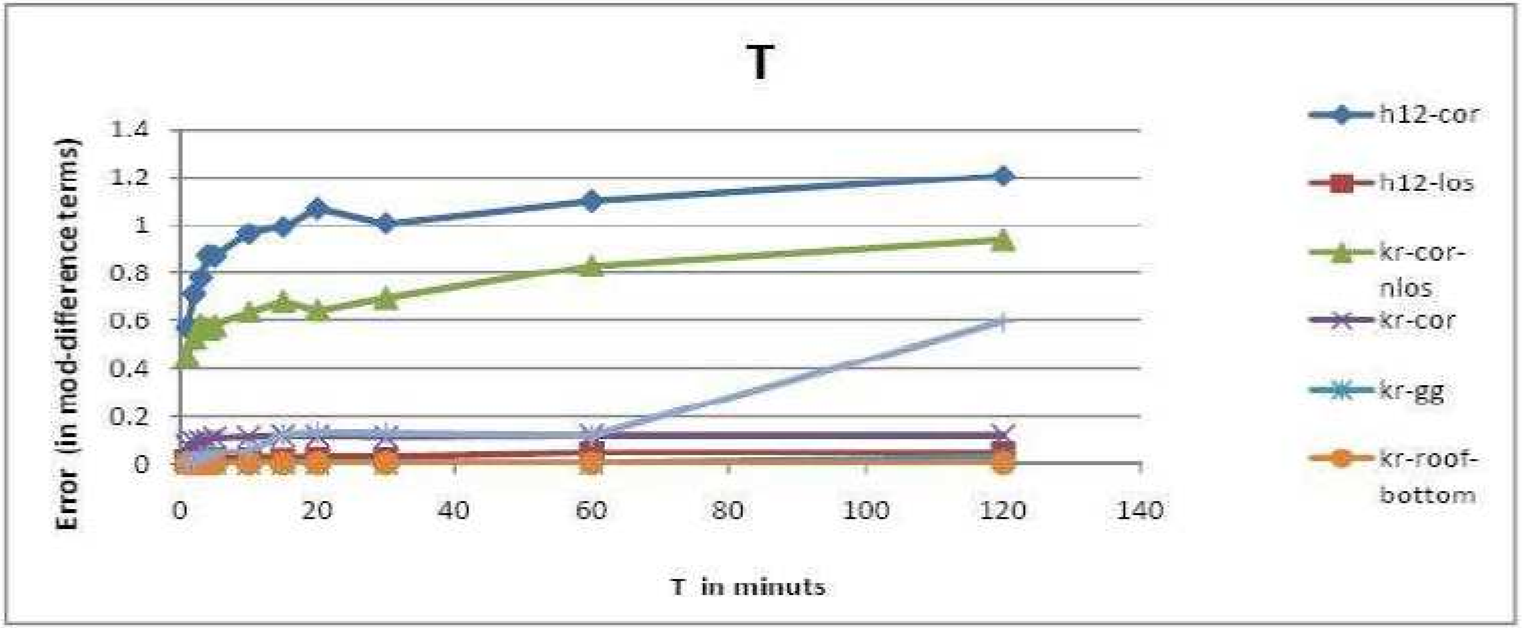
Measurement duration *(t)*



Measurement time period (*T*)

- RSSI data is first divided into windows of size *t* we call them $w_1, w_2, w_3, \ldots w_n$
- Suppose :
  - If T is 1 minute and t is 10 seconds → First six windows would use w_1's predicted SIR band.
  - For a particular *T*, error is the sum of error-difference between the actual window and the window used for prediction.


T
Error (in mod-difference terms)
T in minuts
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100
120
140
POS1
POS2
POS3
POS1-SBRA
POS2-SBRA
POS3-SBRA


T
Error (in mod-difference terms)
T in minuts
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
20
40
60
80
100
120
140
h12-cor
h12-los
kr-cor-nlos
kr-cor
kr-gg
kr-roof-bottom

Measurement time period (*T*)

- The error increases with increase in T.
- The increase in error slows down after T crosses roughly 30 minutes
- T can be sufficiently large – to maintain the network down time.
- Passive measurements can be used to trigger measurement cycle instead of a fixed cycle

Putting it together

Automation : Introduction

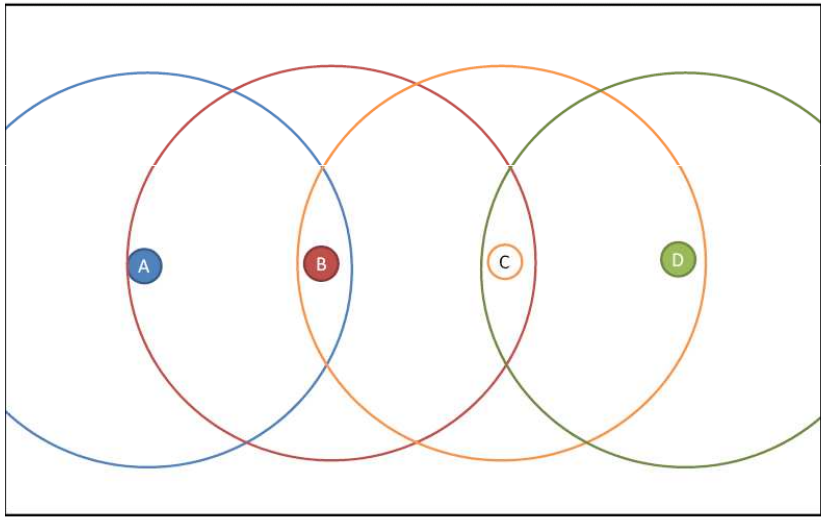
Objectives

- To perform regular controlled measurements at all the nodes according to the schedule given by the central node.
- To generate the interference map, that provides complete information on inter-link interference among all the links in the network, at the central node.
- To create the schedule of transmission for next interference measurements.

Assumptions

- The network will have a central authority, which can control other nodes in the network and can bring the network down for measurements.
- The central node is a computationally more capable node, and generates the interference map from the data sent by other nodes.
- The network has time-synchronization; clocks on all nodes must be synchronized to a global clock.

Interference Map



A	A	B	C	D
A	X	X	X	X
B	X	X	3	N
C	X	1	X	3
D	X	N	3	X

B	A	B	C	D
A	X	X	N	N
B	X	X	X	X
C	N	X	X	N
D	N	X	1	X

C	A	B	C	D
A	X	1	X	N
B	3	X	X	N
C	X	X	X	X
D	N	N	X	X

D	A	B	C	D
A	X	3	N	X
B	3	X	1	X
C	N	3	X	X
D	X	X	X	X

Automation : Active measurement

Central Server

1. Creates broadcast schedule according to t and T
   a) *Broadcast time-stamp*
   b) *Start time*
   c) *End time*
2. Sends schedule to each node using TCP connection
3. Collect the results of measurements (RSSI matrix).

Client Nodes

1. Continuously listens for schedule
2. Once schedule is received
   i. Start listening at Start time
   ii. Broadcast 1400 byte packets for ‘t’ seconds
   iii. Stop listening at End time
   iv. Generate RSSI matrix
3. Send RSSI matrix to central node

Conclusions and Future Work

Conclusion

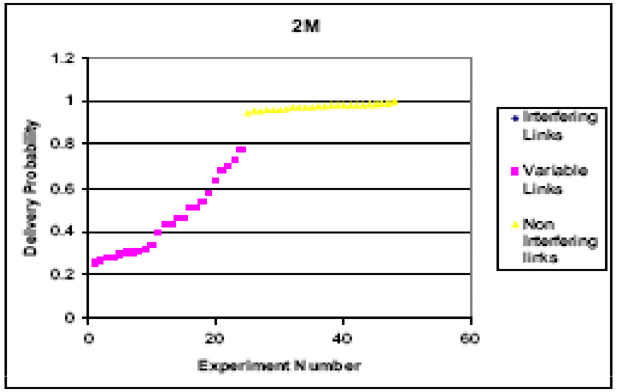
- We have performed controlled measurement and studied interference properties
- Developed a 3-way classification strategy for generating interference map
- Performed time-period analysis for determination of ideal
  - Measurement duration
  - Measurement interval
- Developed an automated procedure to generate interference map.

Future Work

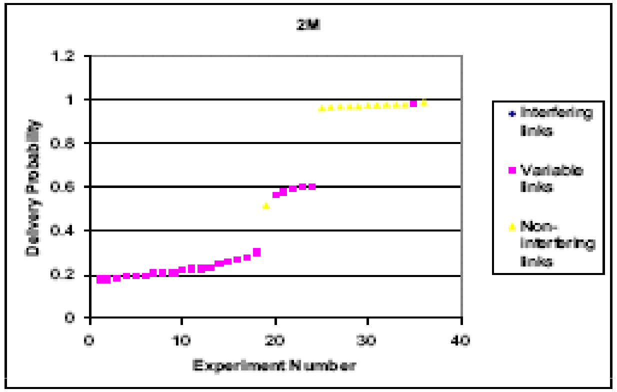
- Proper hardware calibration and further evaluation
- Integration with passive measurement
- Evaluating gain in using spatial reuse map in real TDMA-based networks
- 802.11g and 802.11a measurements

Thank You

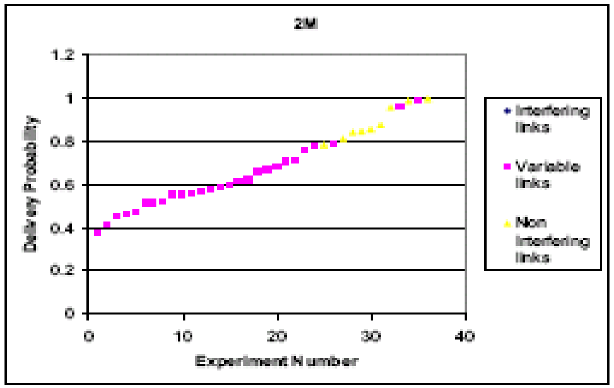
Results 2 Mbps



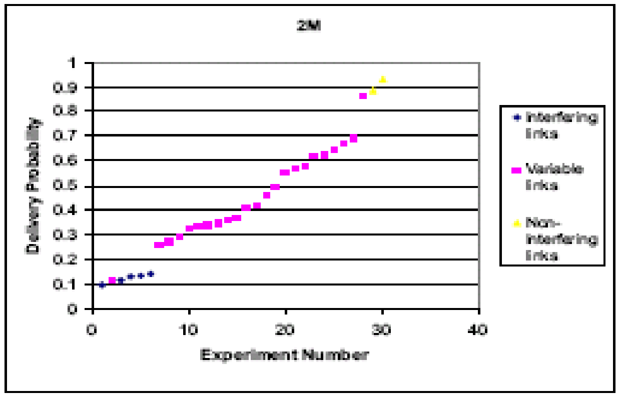
(a) Location1, Type1



(b) Location 1, Type 2



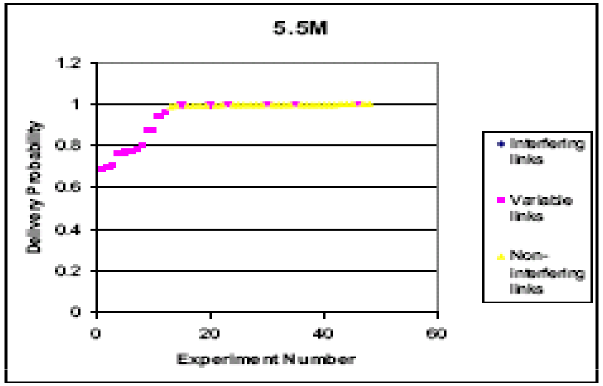
(c) Location 2, Type 3



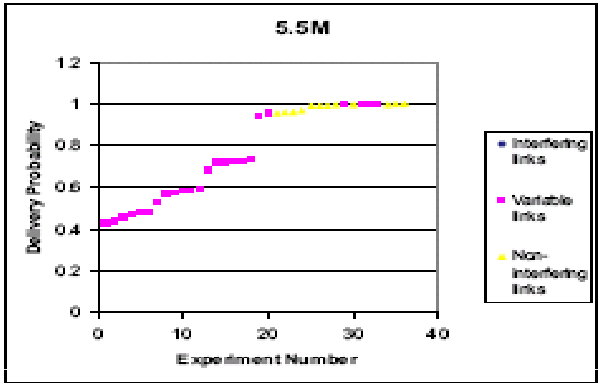
(d) location 2, Type 4

RATE	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
ACCURACY	94.8%	90.7%	87.2%	84.6%

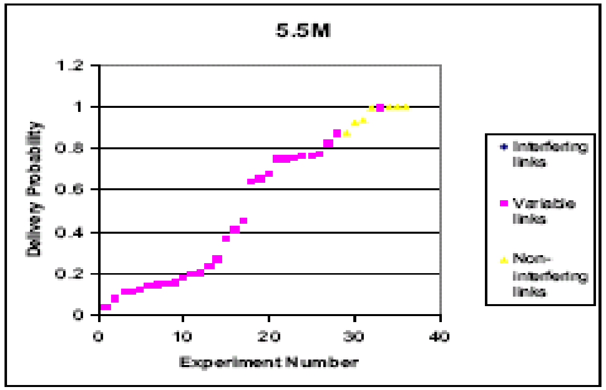
Results 5.5 Mbps



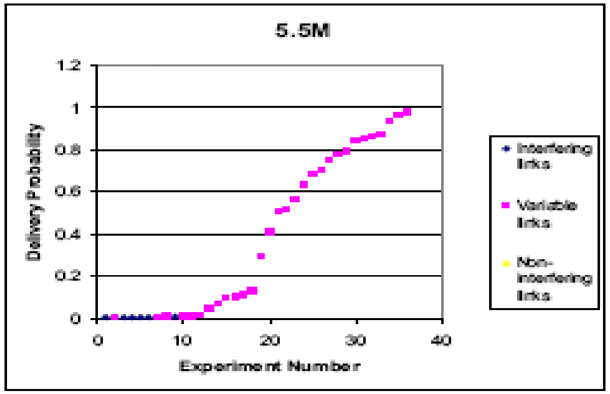
(a) Location1, Type1



(b) Location 1, Type 2



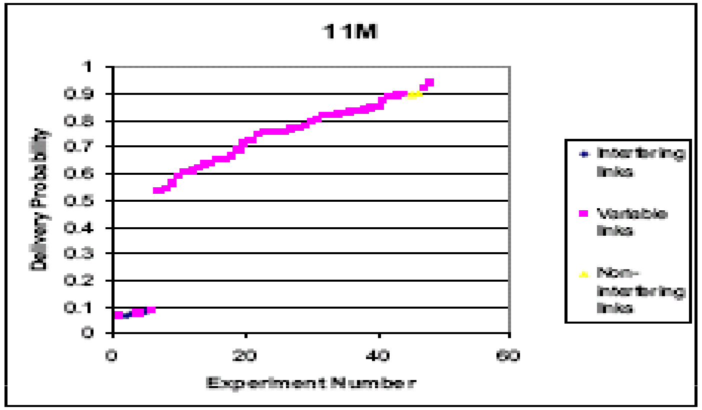
(c) Location 2, Type 3



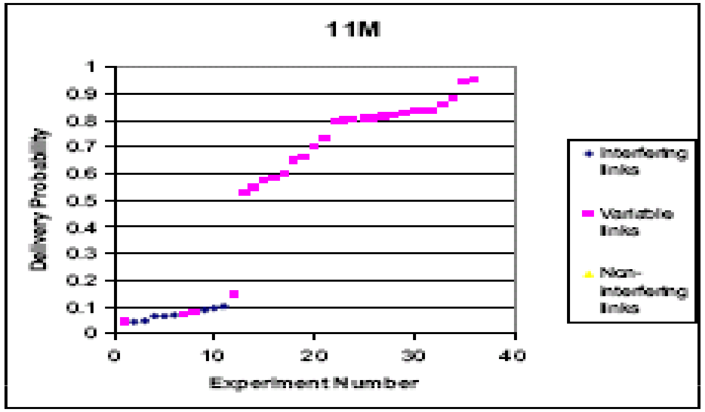
(d) location 2, Type 4

RATE	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
ACCURACY	94.8%	90.7%	87.2%	84.6%

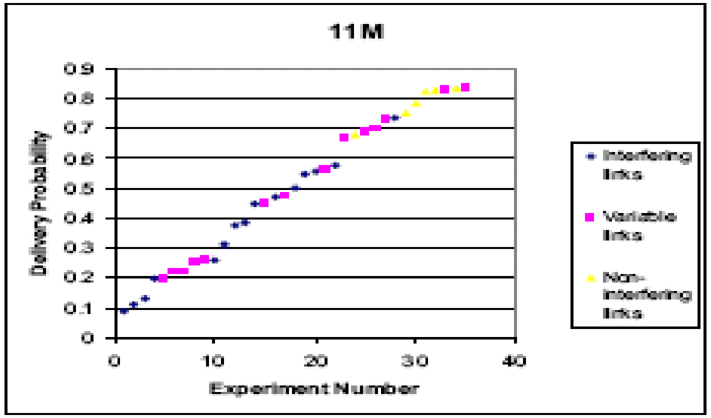
Results 11 Mbps



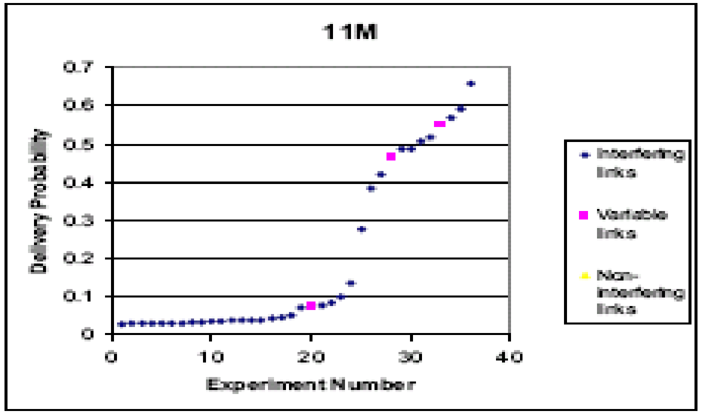
(a) Location1, Type1



(b) Location 1, Type 2



(c) Location 2, Type 3



(d) location 2, Type 4

RATE	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
ACCURACY	94.8%	90.7%	87.2%	84.6%

1Mbps

Type of experiment	Number of Experiments	Accuracy (Roofnet)	Accuracy (Roofnet -1)	Accuracy (Roofnet +1)	Accuracy (Roofnet -2)	Accuracy (Roofnet +2)
Location 1 (Type 1)	48	66.6%	60.4%	81.25%	58.33%	**87.5%**
Location 1 (Type 2)	36	75.0%	61.1%	97.2%	44.44%	**97.2%**
Location 2 (Type 3)	36	86.1%	91.7%	91.7%	69.44%	**100%**
Location 2 (Type 4)	36	88.0%	80.5%	91.7%	77.78%	**94.4%**
All	156	78.20%	72.4%	89.7%	59.62%	**94.8%**

2 Mbps

Type of experiment	Number of Experiments	Accuracy (Roofnet)	Accuracy (Roofnet -1)	Accuracy (Roofnet +1)	Accuracy (Roofnet -2)	Accuracy (Roofnet +2)
Location 1 (Type 1)	48	**97.9%**	91.7%	95.8%	83.33%	85.4%
Location 1 (Type 2)	36	**94.4%**	97.2%	86.1%	88.89%	83.3%
Location 2 (Type 3)	36	**77.8%**	77.8%	75.0%	80.56%	75.0%
Location 2 (Type 4)	30	**90.0%**	90.0%	86.7%	86.67%	83.3%
All	152	**90.7%**	89.3%	86.7%	84.67%	80.0%

5.5 Mbps

Type of experiment	Number of Experiments	Accuracy (Roofnet)	Accuracy (Roofnet -1)	Accuracy (Roofnet +1)	Accuracy (Roofnet -2)	Accuracy (Roofnet +2)
Location 1 (Type 1)	48	66.6%	**85.4%**	75.0%	91.67%	68.7%
Location 1 (Type 2)	36	77.08%	**86.1%**	69.4%	94.44%	58.3%
Location 2 (Type 3)	36	75.1%	**88.9%**	75.0%	86.11%	72.2%
Location 2 (Type 4)	36	88/0%	**88.9%**	88.9%	72.22%	88.8%
All	158	80.8%	**87.2%**	76.9%	86.54%	71.7%

11 Mbps

Type of experiment	Number of Experiments	Accuracy (Roofnet)	Accuracy (Roofnet -1)	Accuracy (Roofnet +1)	Accuracy (Roofnet -2)	Accuracy (Roofnet +2)
Location 1 (Type 1)	48	72.9%	68.7%	83.3%	68.75%	**95.8%**
Location 1 (Type 2)	36	75.0%	72.2%	91.6%	72.22%	**83.3%**
Location 2 (Type 3)	36	75.0%	66.6%	75.0%	66.67%	**83.3%**
Location 2 (Type 4)	36	83.3%	97.2%	75.0%	97.22%	**72.2%**
All	158	76.9%	76.9%	80.7%	76.92%	**84.6%**