



# Characterization of 802.11 Wireless Networks in the Home

M. Yarvis. K. Papagiannaki and W. Conner  
Intel Research

*Presenter - Bob Kinicki*  
*rek@cs.wpi.edu*

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# Outline

- Introduction
- Experimental Environment
- Results
- Conclusions

# Introduction

- Little was known about the properties of home wireless networks in 2005.
- Conjecture is that wireless home behavior will be similar to enterprise wireless network behavior.
- The goal is to specifically examine the impact of transmission rate and transmission power on the quality of home wireless links.

# Experimental Environment

- Experimental Setup
- Methodology
- Validation



# Experimental Setup

## Measurements in Three Homes

Table I

Description of homes used in experimental testbeds.

Label	Size (ft <sup>2</sup> )	Construction	# Floors	# Nodes
<i>ushome1</i>	2,500	Wood	2	6
<i>ushome2</i>	2,000	Wood	2	6
<i>ukhome1</i>	1,500	Brick / steel	3	6

- ***Six wireless nodes inside each home***
- ***Ad Hoc communication (No AP)***

# Experimental Methodology

- Data link layer retransmissions disabled.
- 300 1024-byte UDP probe packets sent every 500ms (150 seconds).
- No simultaneous transmissions
- Experiments run during the night to avoid interference from moving people.
- Allows **quantifying loss rate** observed by each wireless link.

# ushome1 Experiments

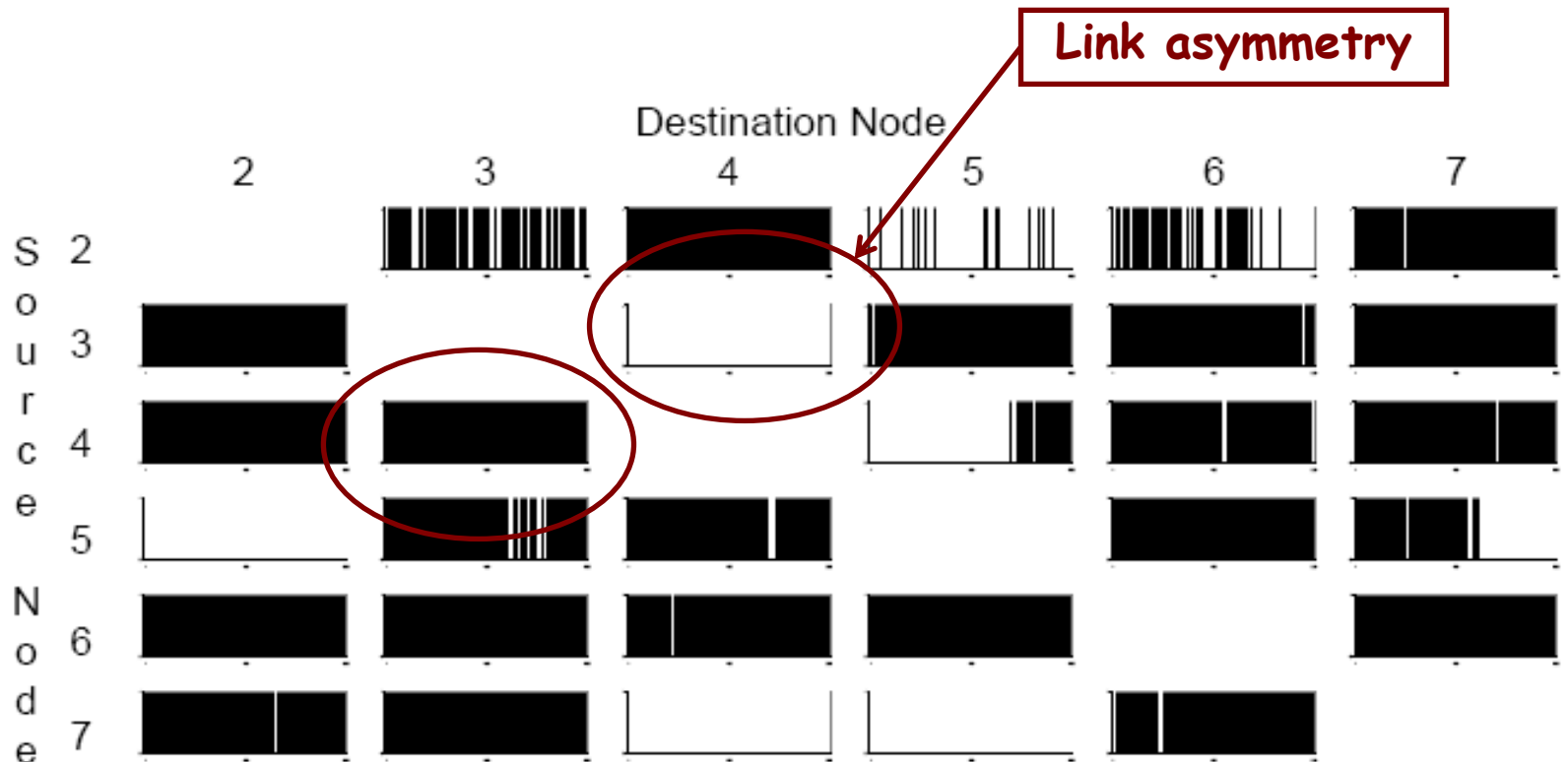
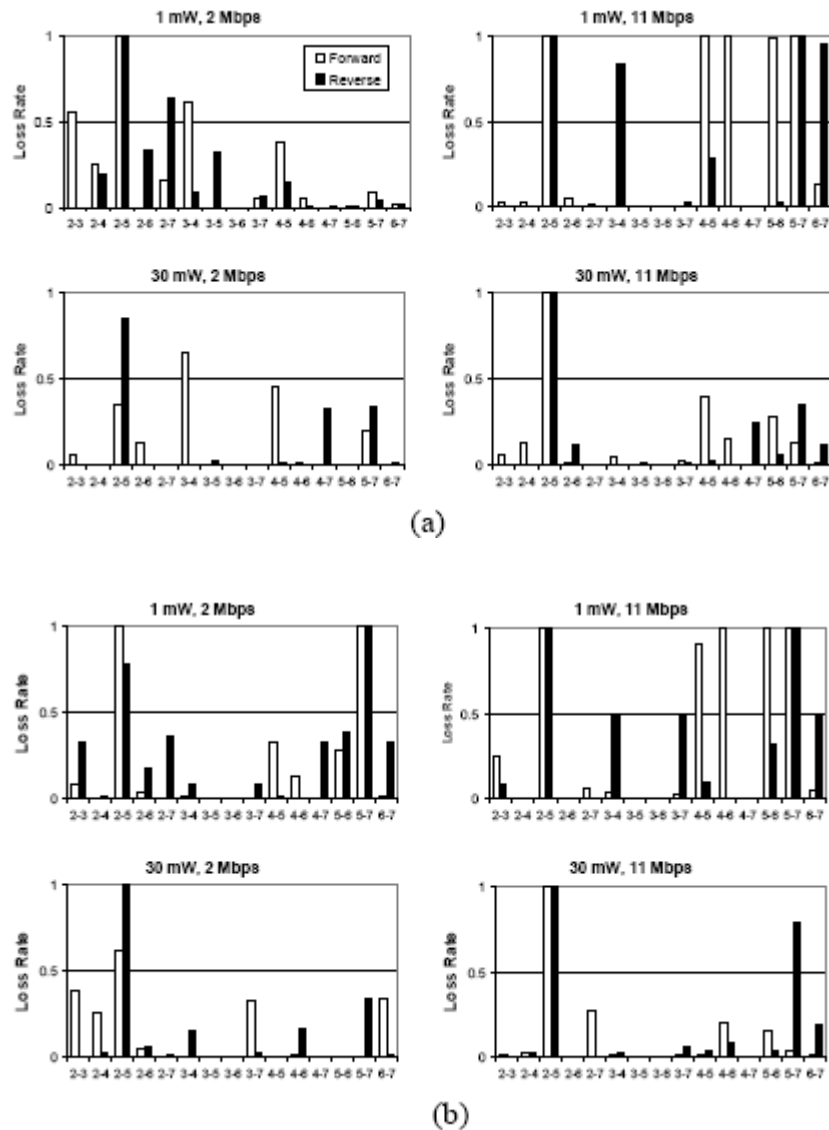


Fig. 1. Matrix of probe packets successfully delivered between each pair of nodes in *ushome1* at 30mW and 2Mbps.

# Methodology Validation

- Duplicated results
- Experimental length
- Time of Day variability





Link performance does not change significantly.

Fig. 2. Loss rates for each pair of nodes in two runs at *ushome1*

# Experiment Length ?

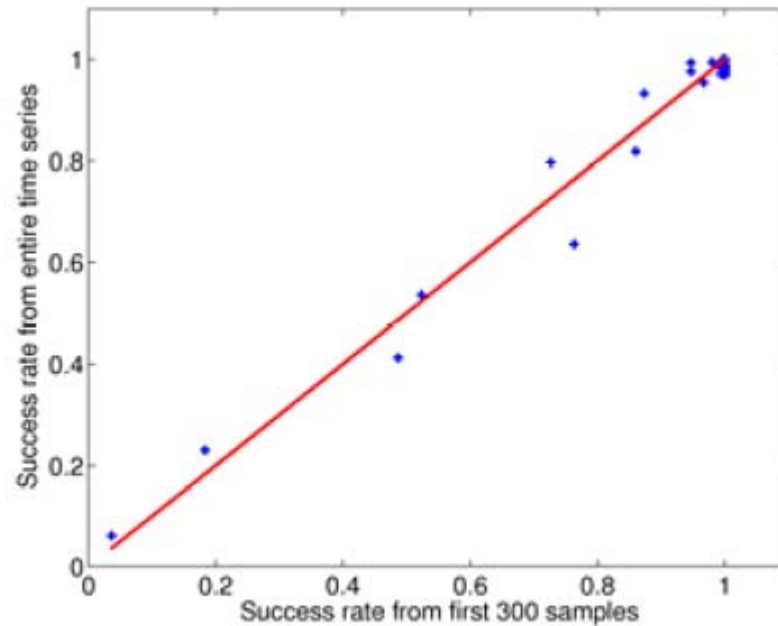


Fig. 3. Comparison of success rate results for 300 and 2400 sample lengths. The straight line provides a reference for equality ( $y=x$ ).

# Time of Day Effect ?

Good link remains good, bad link remains bad.

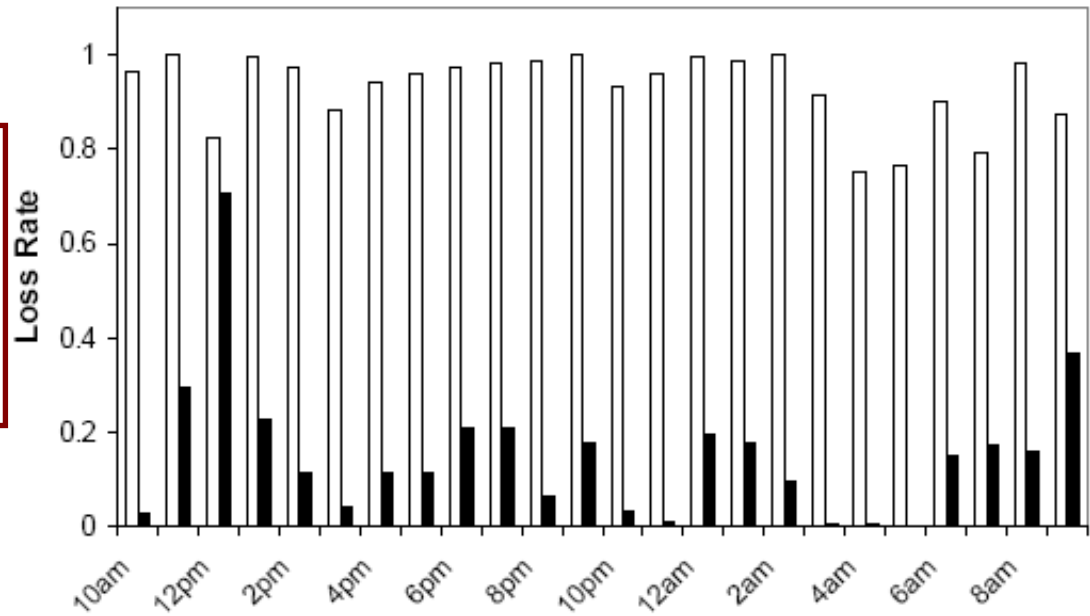


Fig. 4. Loss rate as a function of time of day for *ushome1* ( $txpower=30mW$ ,  $txrate=11M$ ). First bar is node-4 to node-6, second bar is node-6 to node-4.

# Results

Evaluates the home wireless environment along six dimensions:

1. Transmission rate (txrate)
2. Transmission power (txpower)
3. Node location
4. House type
5. External interference
6. Physical layer



# Overall Characteristics

- Link loss rates were higher when the encoding rate was higher.
- Link loss rates were lower when the power level increased.
- Wireless connectivity is NOT omnipresent.
- Several asymmetric links were observed.
- In most experiments, at least one node pair had 30% loss.

# ukhome1

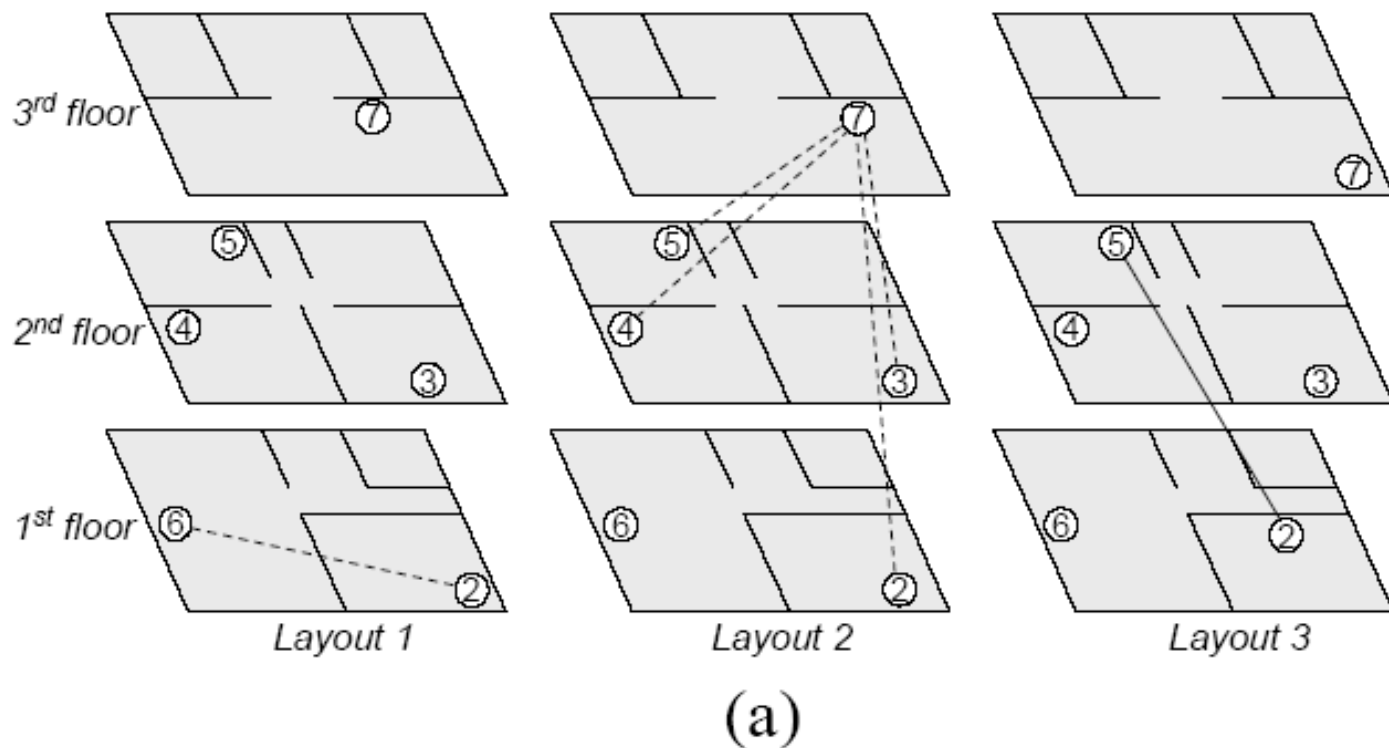


Fig. 7. Abstract home floorplans and location of links with greater than 95% loss rate at 1 mW and 11 Mbps under different configurations: (a) *ukhome1* for layout1, layout2, and layout3, (b) *ushome1*, and (c) *ushome2* for layout1 and layout2. Dashed lines indicate asymmetric links.

# ushome1

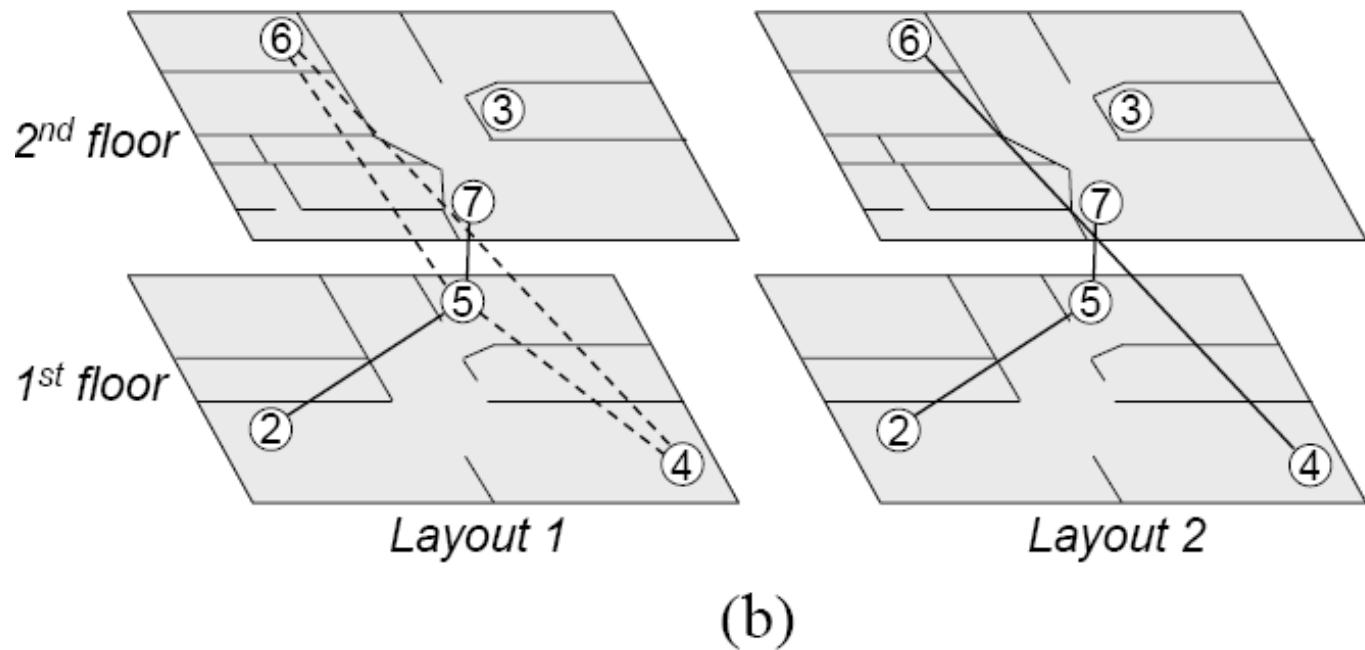


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# ushome2

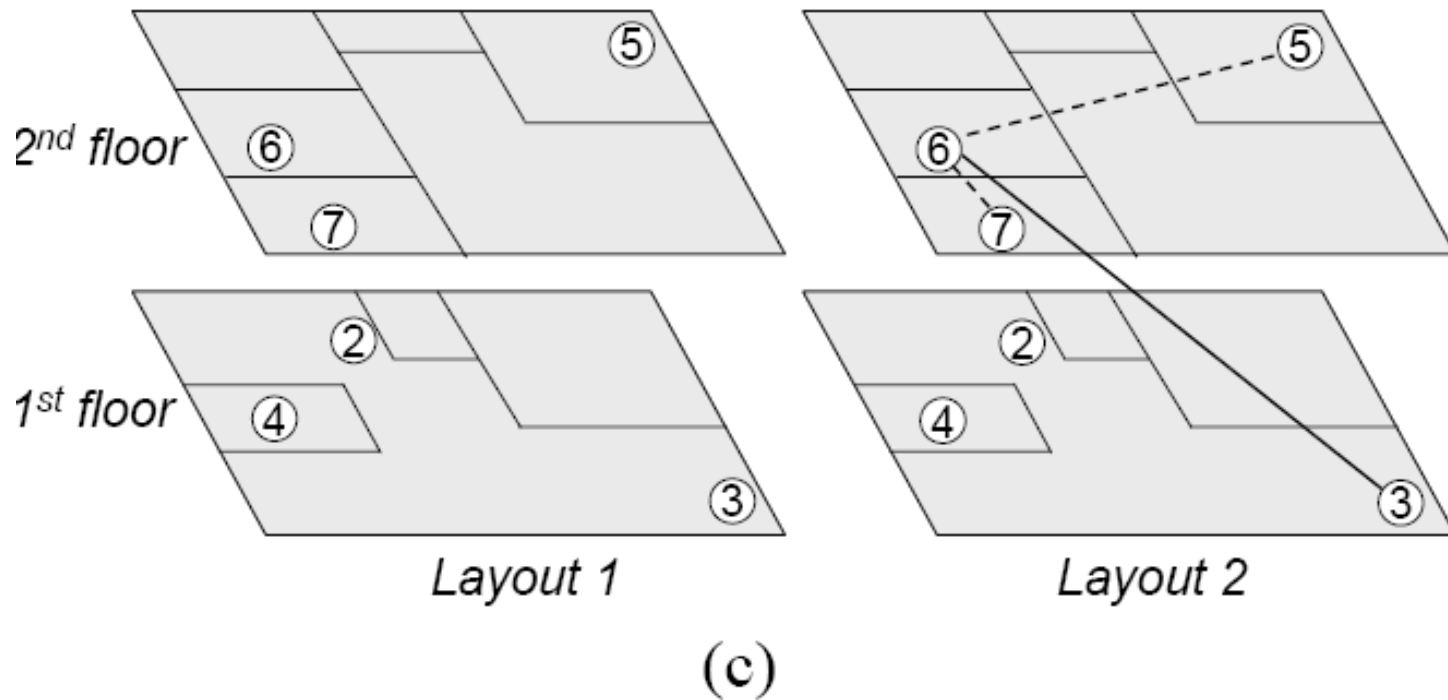
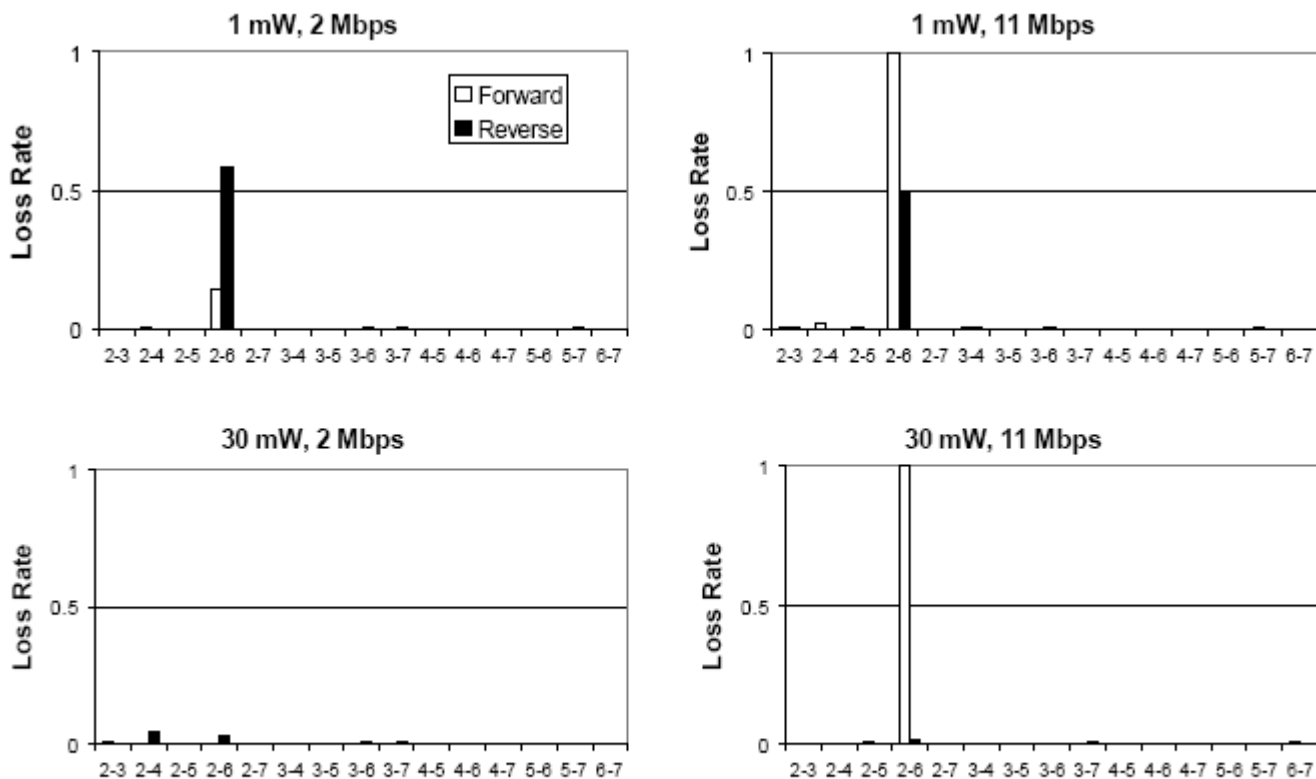


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# Figure 5

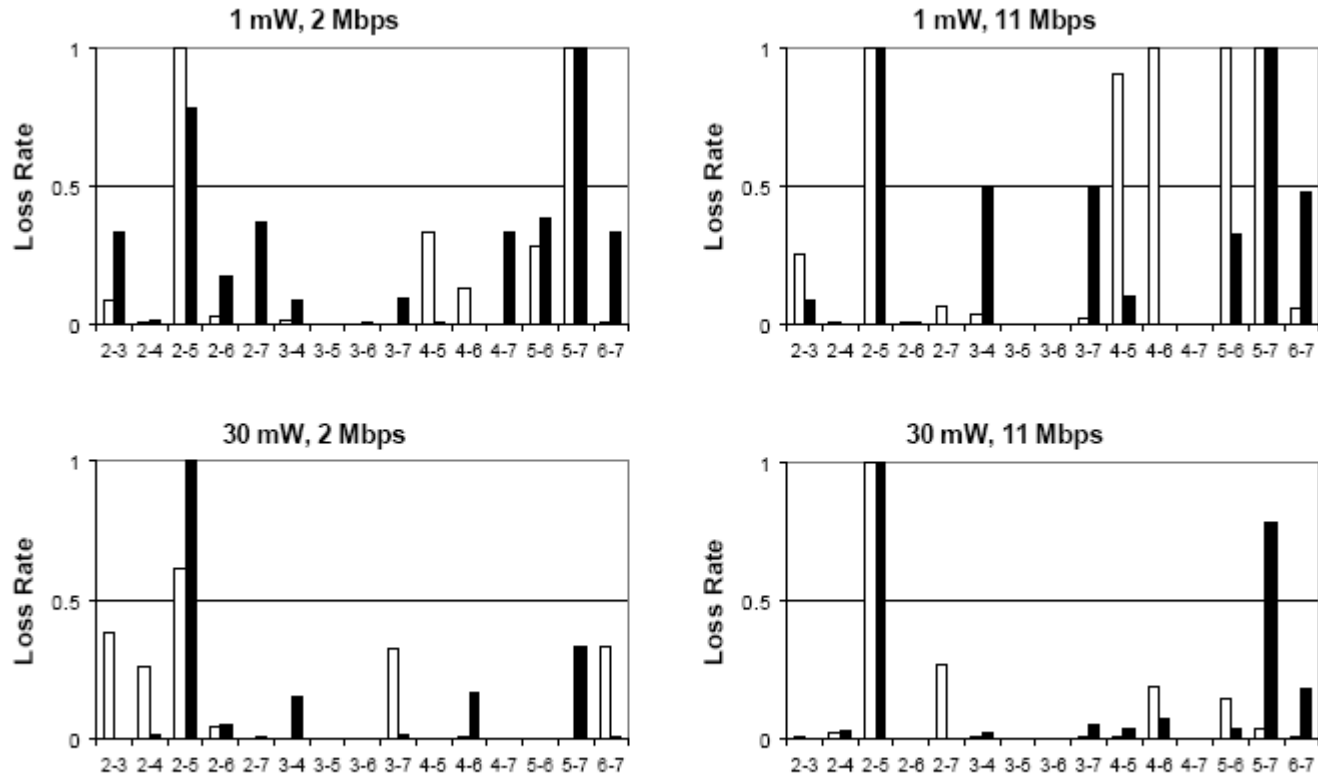
## Loss Rates Layout1 ukhome1



(a)

# Figure 5

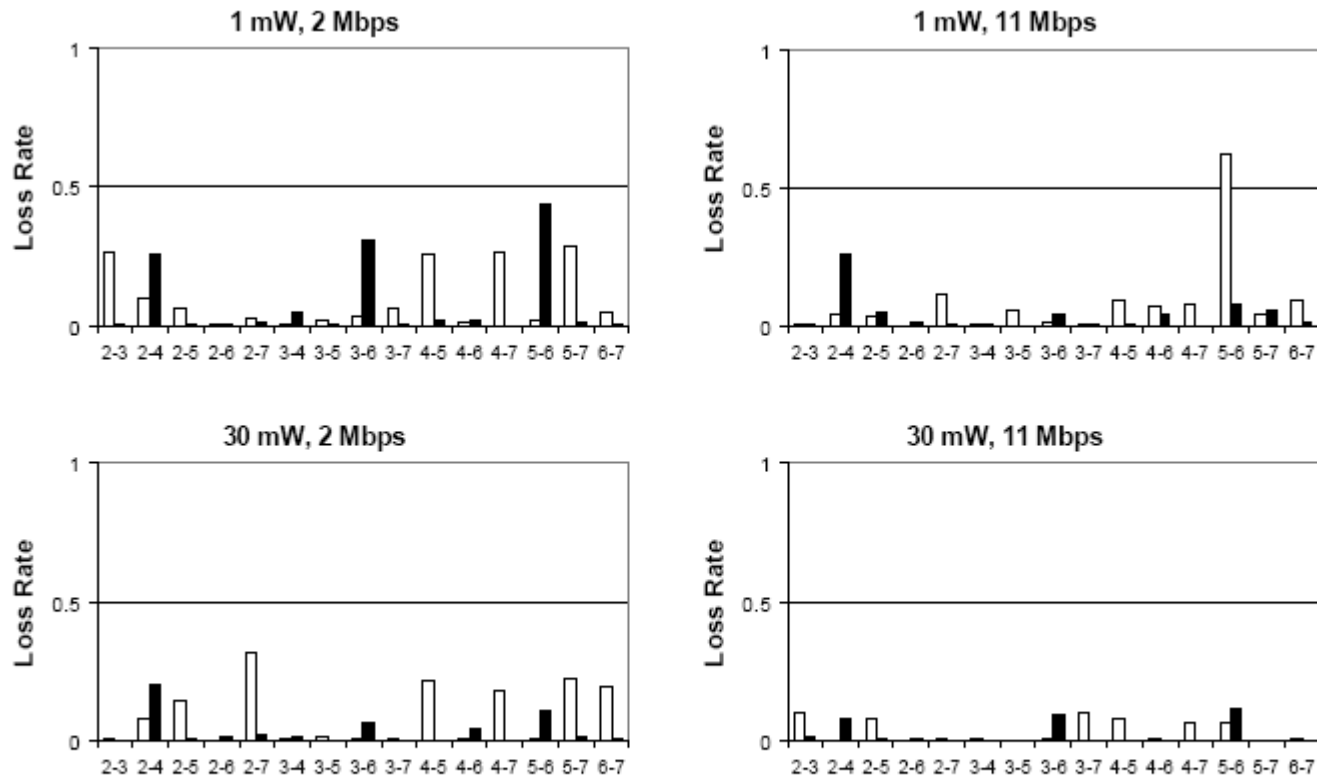
## Loss Rates Layout1 ushome1



(b)

# Figure 5

## Loss Rates Layout1 ushome2



(c)



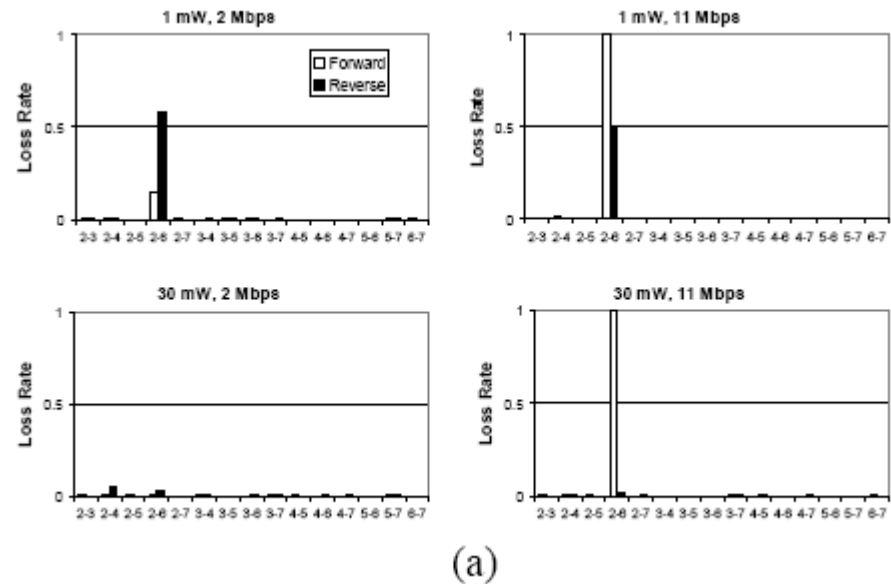
# Small changes in antenna orientation and location

- For layout2, layout1 nodes are translated **a few inches** and antennas are rotated to face another direction.
- Conclusion:: exact node placement is a key contributor to performance

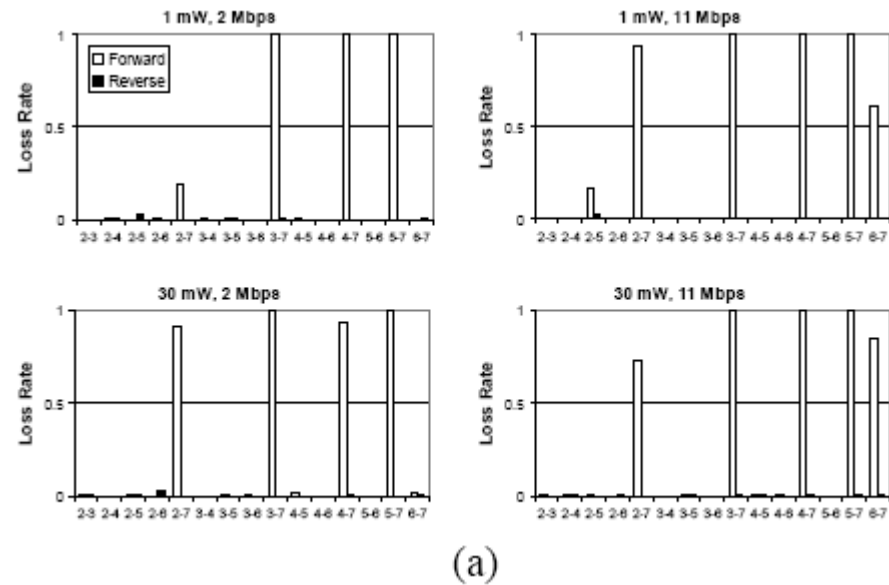




# Figure 5a ukhome1 Layout1



# Figure 6a ukhome1 layout2



# ukhome1

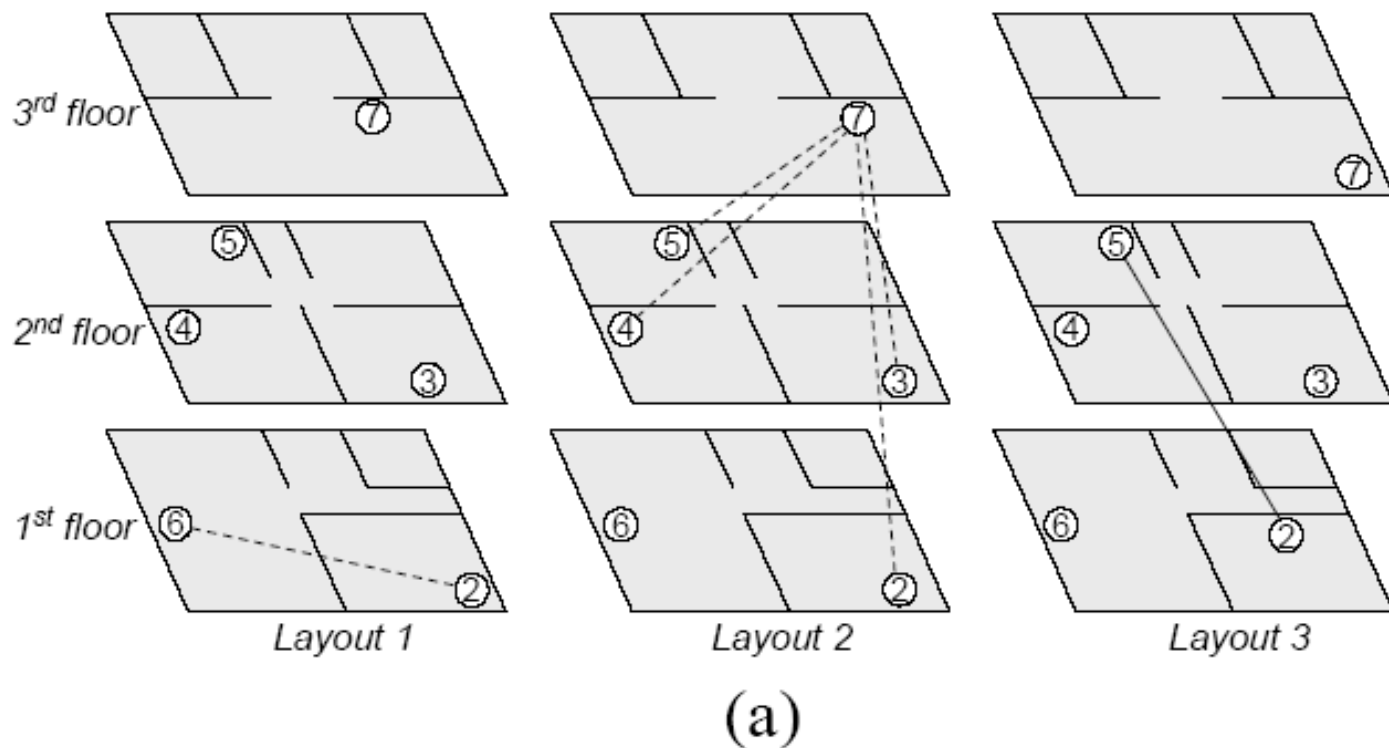


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# Large changes in node placement

- For ukhome1 nodes 2 and nodes 7 were moved to a different location within the same room from layout1 to produce layout3.
- The other nodes were moved slightly from their layout1 positions.

# ukhome1

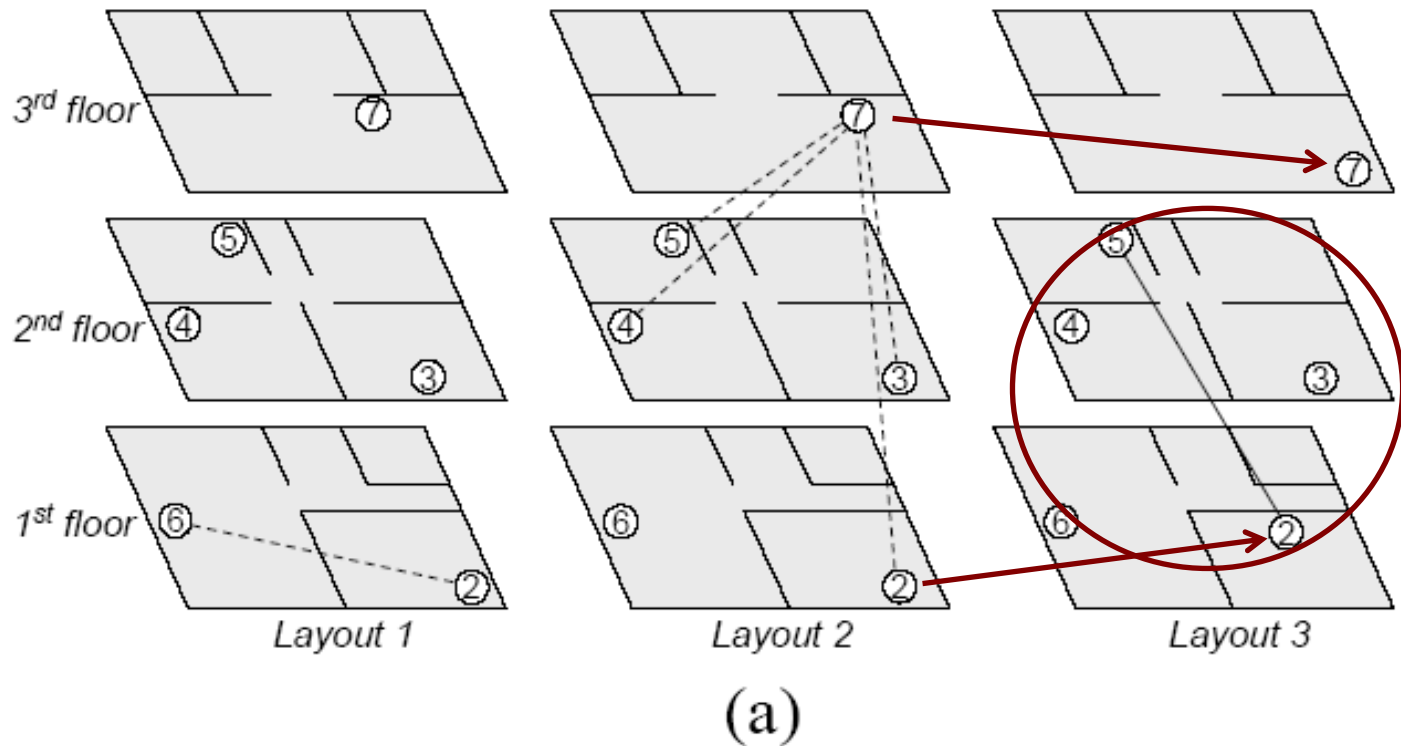


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# Figure 5a ukhome1 Layout1

More significant loss in links and quality

# Figure 8 ukhome1 layout3

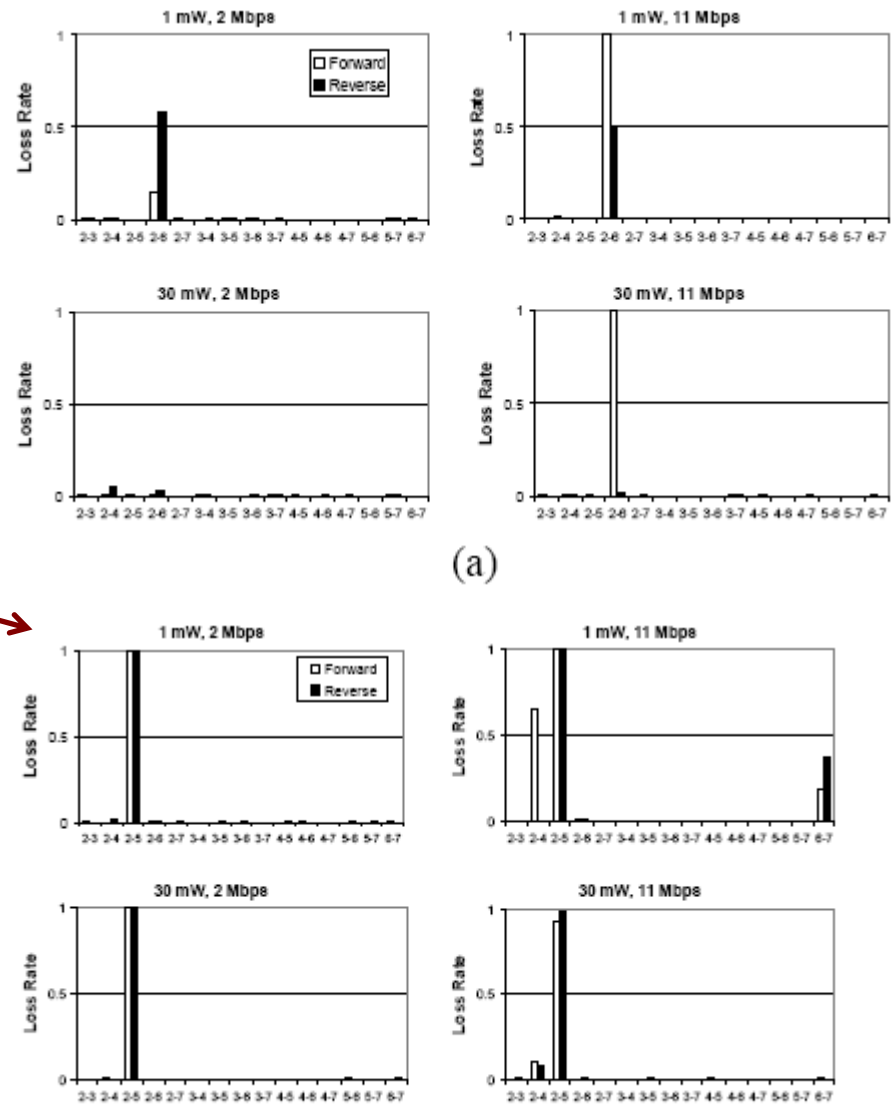
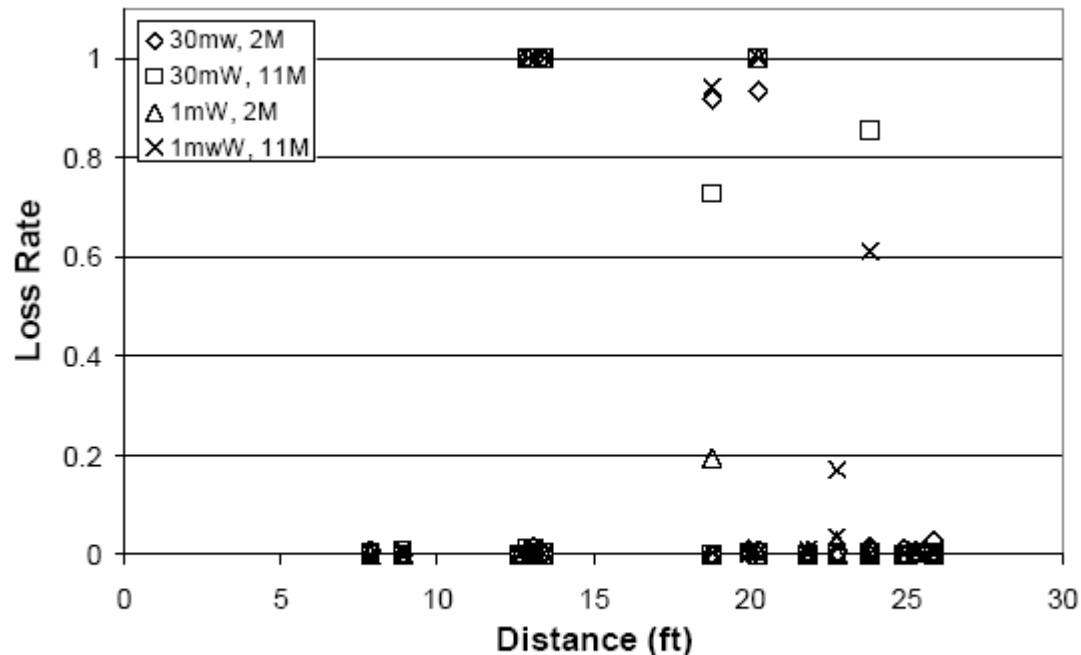


Fig. 8. Loss rate for each pair of nodes in *ukhome1*, *layout3*.

# Link quality and distance relationship

- Results in Figure 9 for layout2 for all three homes show there is **no correlation between physical distance and wireless link quality**.
- This result holds across homes and across txrate and txpower settings.

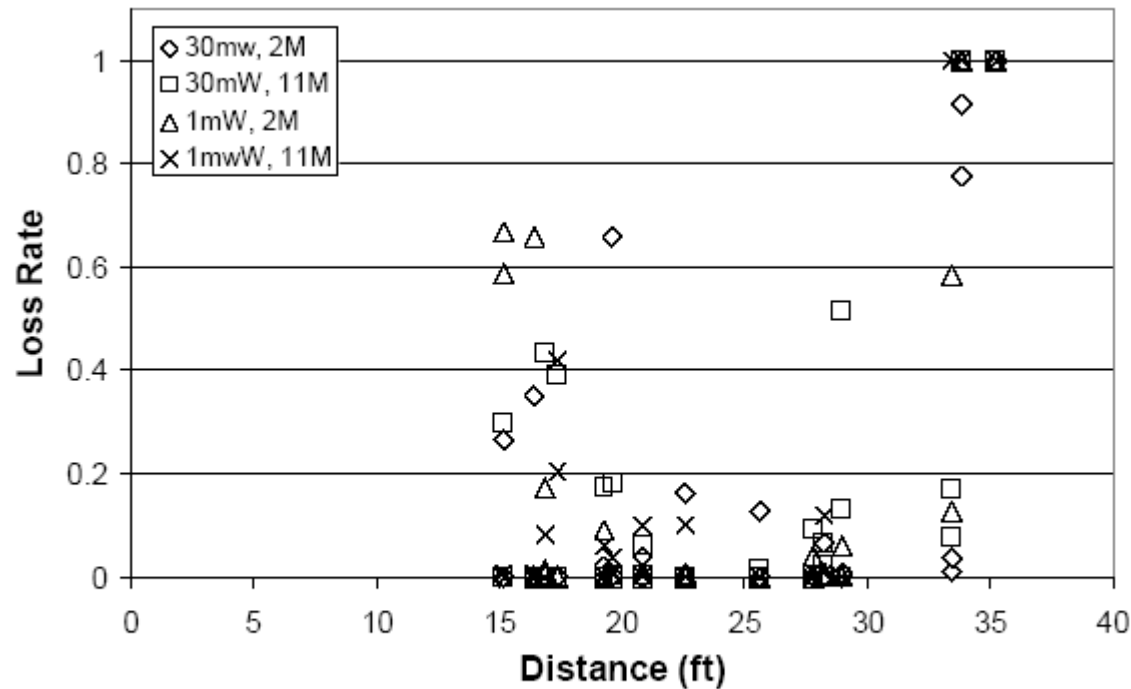
# Link quality and distance relationship layout2



(a)

## Figure 9: ukhome1

# Link quality and distance relationship layout2

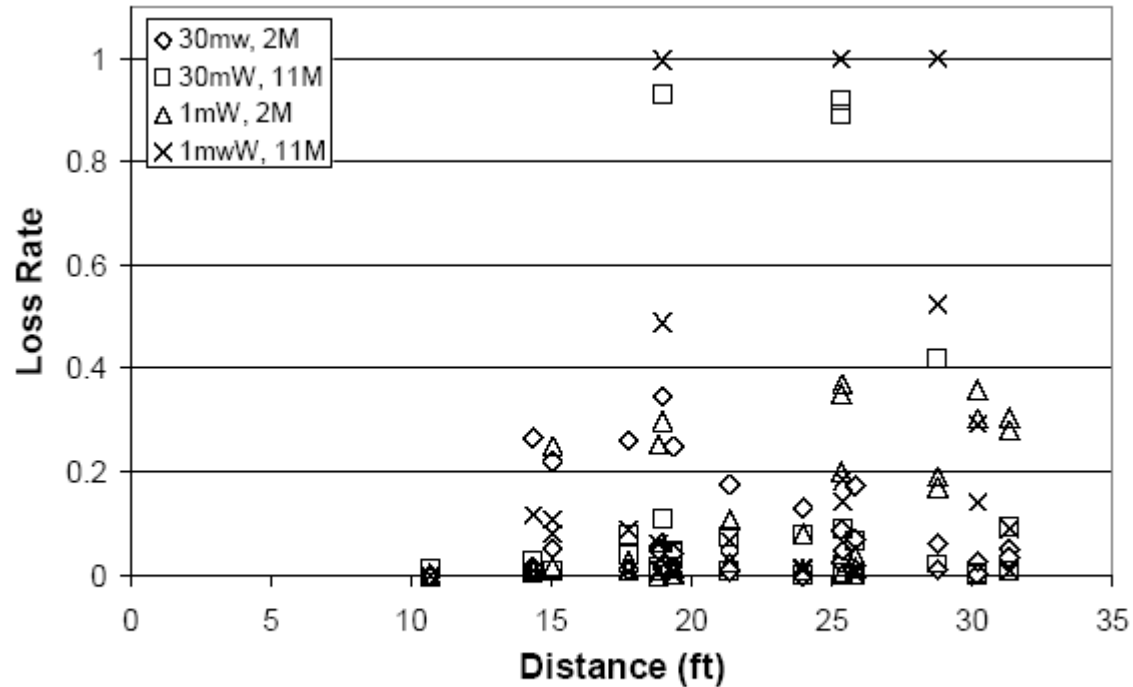


(b)

## Figure 9: ushome1



# Link quality and distance relationship layout2



(c)

## Figure 9: ushome2

# Microwave Oven Interference

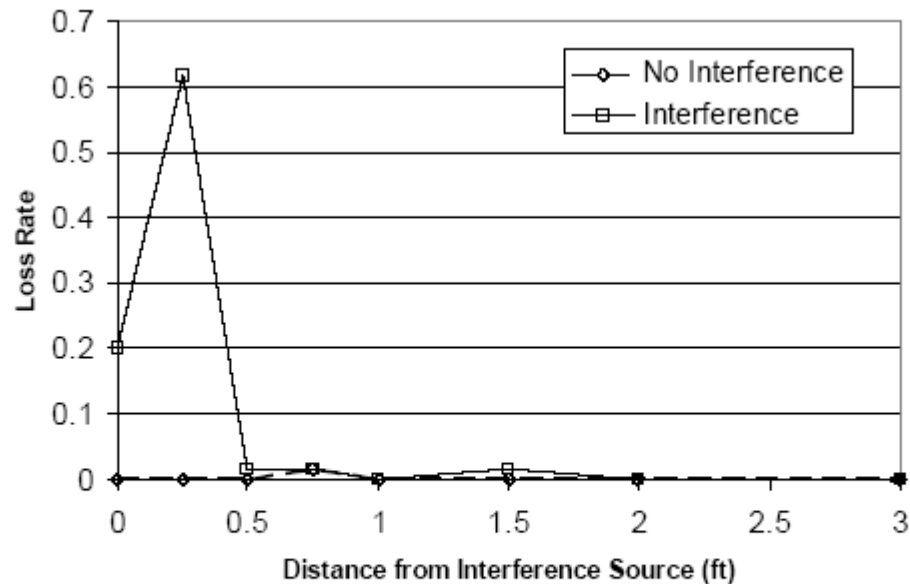


Fig. 10. The impact of a 600W microwave on a receiver at varying distance from the interference source and a distance of 15 feet from the sending node.



# Between home comparisons

- Small home (ukhome1) had better results sometimes (layout1), but worse performance under layout2.
- Precise node location is more important than home size or distance.

# IEEE 802.11a Experiments

- Results were quite similar to 802.11b results!
- 802.11a yielded slightly better performance.
- Although 802.11a results were more 'binary', namely either good or very bad.



# Layout1 ushome1

Figure 5b  
802.11b

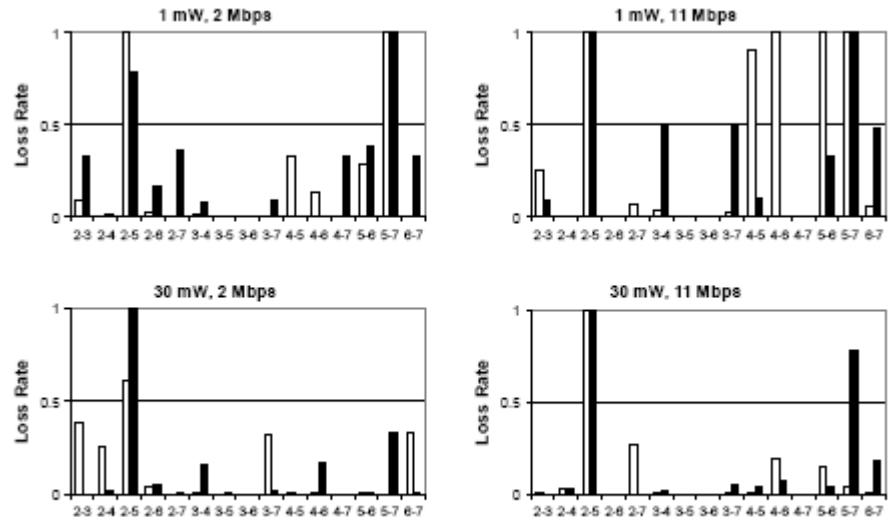
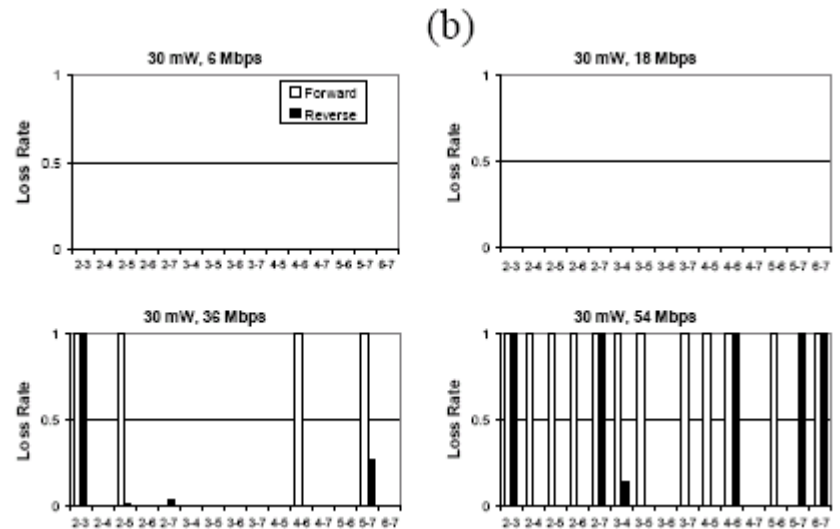


Figure 11a (a)  
802.11a



# IEEE 802.11a Experiments

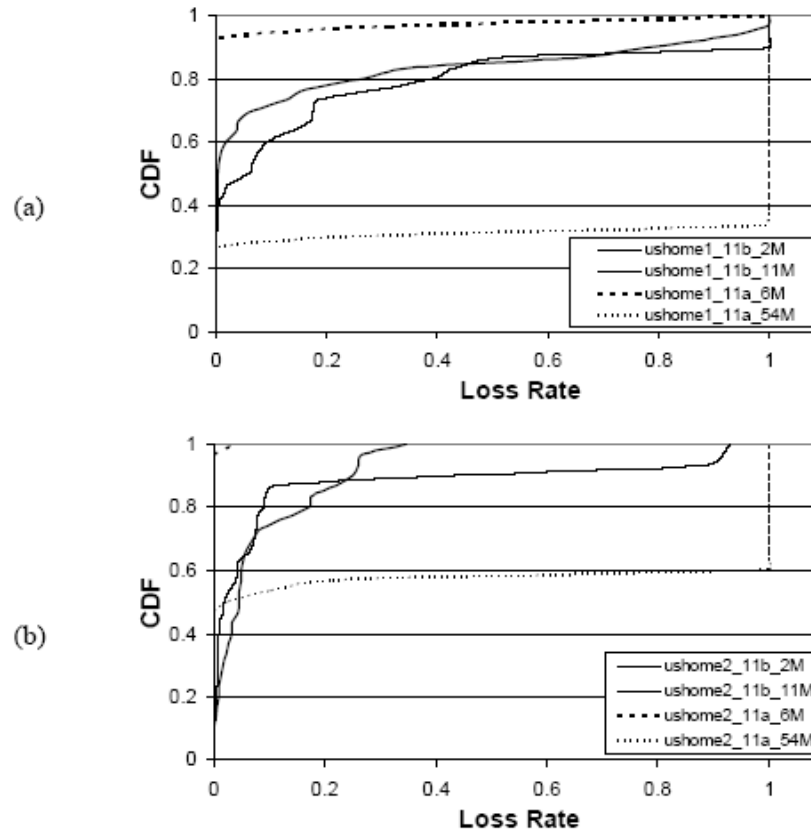


Fig. 14. Cumulative density function of loss rates under IEEE 802.11b and IEEE 802.11a in (a) *ushome1* and (b) *ushome2*.

# Conclusions

- Wireless links inside homes tend to be stable over time, highly asymmetric and highly variable from one link to the next.
- Precise node location is probably the single most important factor.
- Distance has no impact on quality of the wireless links.
- Small changes in antenna orientation and node location can dramatically change individual link performance.

# Conclusions (cont.)

- 802.11a performed slightly better in homes.
- But for both 802.11a and 802.11b the highest allowable rate may not be possible due to high loss.
- Home networks face similar problems to larger networks.
- Results imply the location of the AP will have a significant impact on overall performance.





# Characterization of 802.11 Wireless Networks in the Home

Thank You!

*Questions ??*

