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Cross-Duplexed Spectrum Sharing for Wideband Air-to-Ground Service
- Overview -

April 9, 2004

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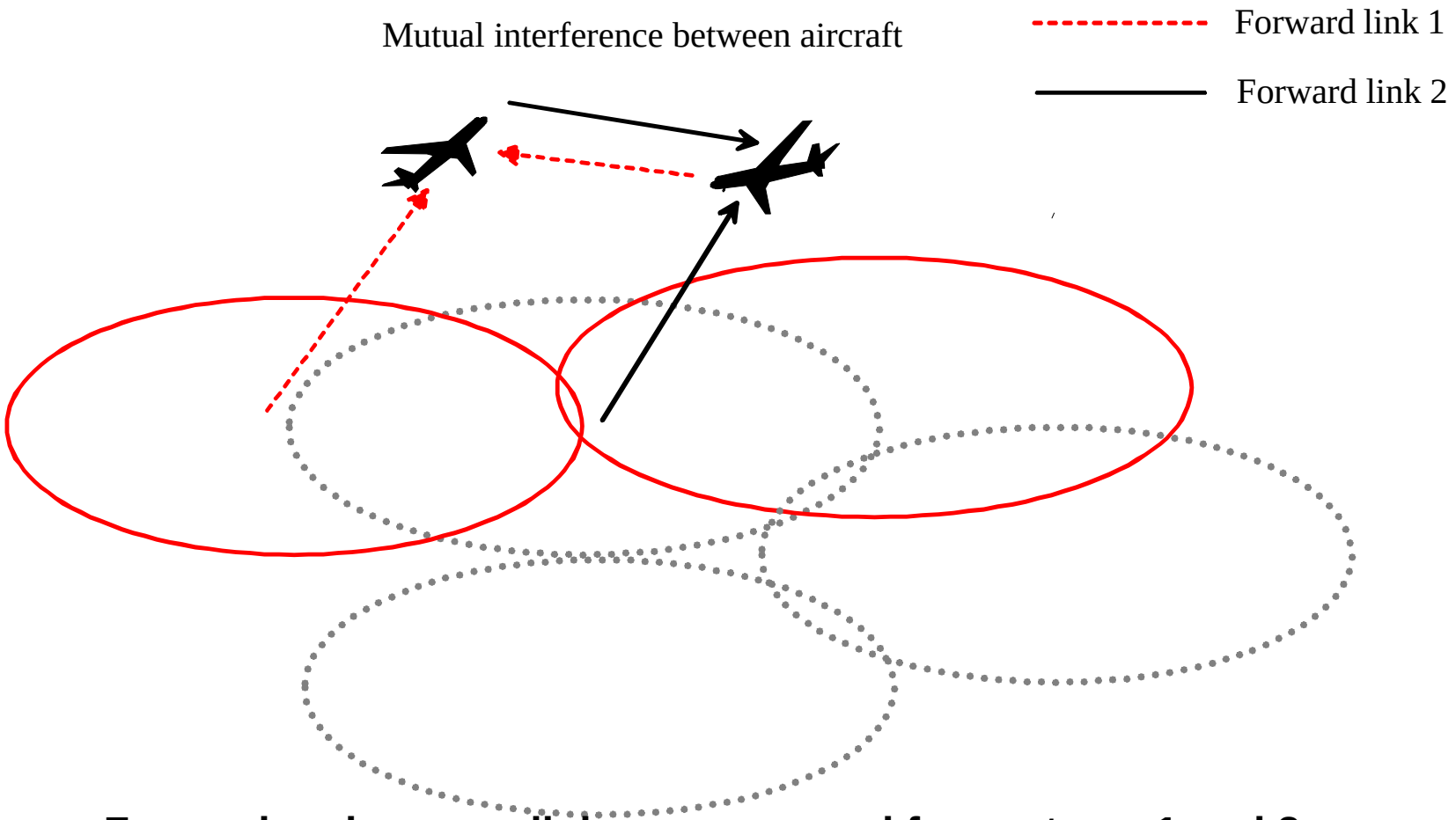
The Cross-Duplex Sharing Concept



- **Forward and reverse links are swapped for systems 1 and 2.**
- **Interference will be aircraft to aircraft and base to base, if the bases are within the radio horizon of each other.**
- **Allows random interference between aircraft of opposite systems.**

Comments on the AirCell Study

- **Ignored base-to-base interference (which will be a factor in the airport scenario – see next slide).**
- **Used a 23-dBm limit on *total* aircraft transmit power (the same as the max transmit power of a cellular handset supporting a single speech call).**
- **Seems to have ignored other-cell same-system interference on the forward link.**
- **Used very "sunny day" assumptions (perfect textbook propagation and implementation, lossless diplexer, low market penetration) and showed minimal interference impact for those conditions.**
- **If the AirCell modeling approach is used but with more realistic assumptions and variations in load, a very different picture emerges (even ignoring the base-to-base interference problem).**

Bottom Line: The cross-duplexing concept is fragile and does not hold up for more realistic conditions and higher usage.

The AirCell Simulation Framework

$$\text{Radio horizon in miles}: R_{\max} = \sqrt{2}\left(\sqrt{h_1} + \sqrt{h_2}\right)$$

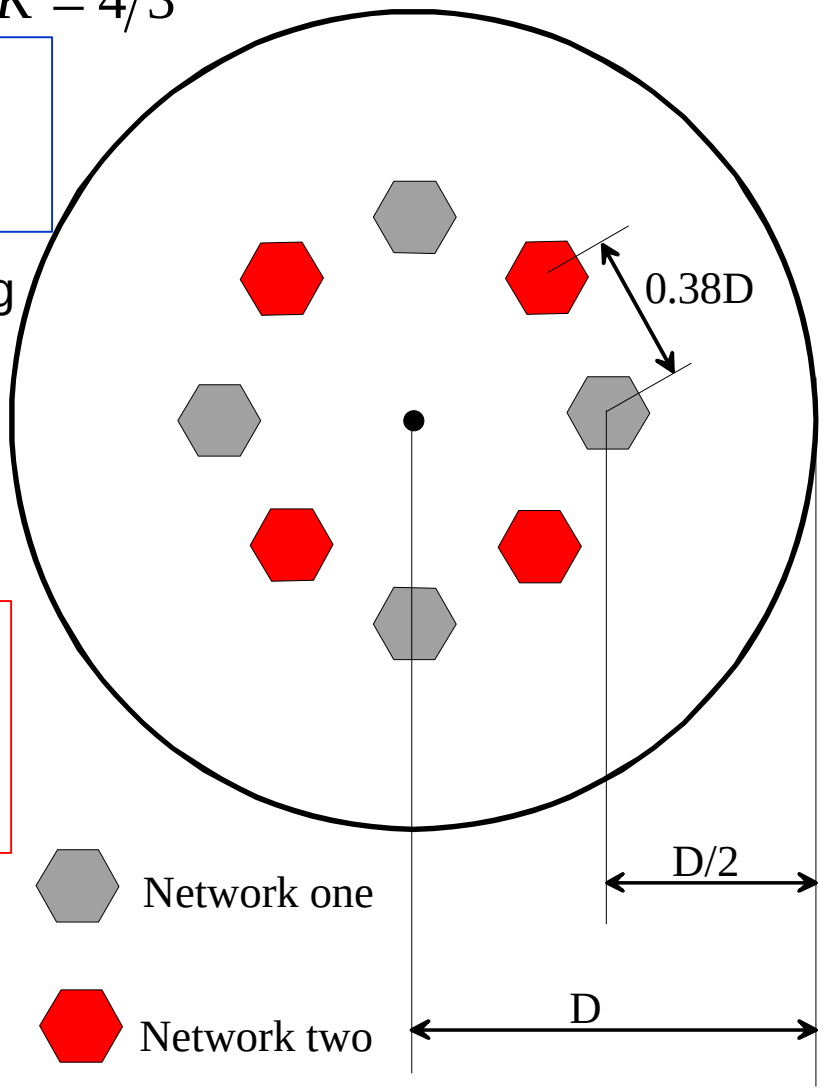
where h_1 and h_2 are in feet, for $K = 4/3$

Tower heights range from 40 to 240 feet, giving radio horizons between towers ranging from 17.9 to 43.8 miles

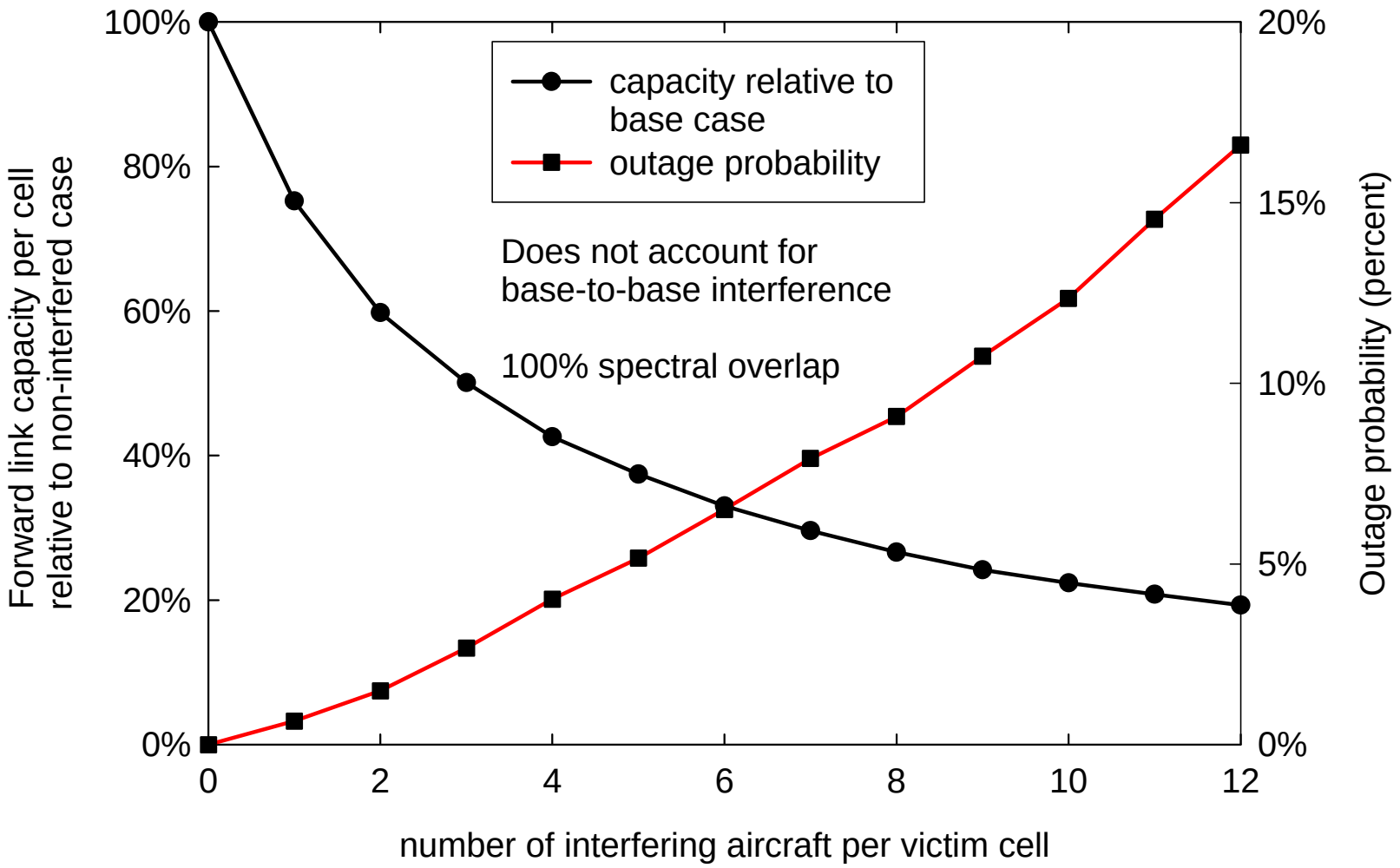
For AirCell's "airport scenario" interfering base stations are 9.5 miles apart. The noise floor of each base station would be raised by 46 dB, shutting down reverse link communication.

Each base station will be within the radio horizon of at least two interfering (cross-duplexed) base stations.

D = 200 miles ("cross country")
D = 25 miles ("airport")



Simulation Results – AirCell Geometry and Voice Circuit Reverse Link Model



Summary and Conclusions

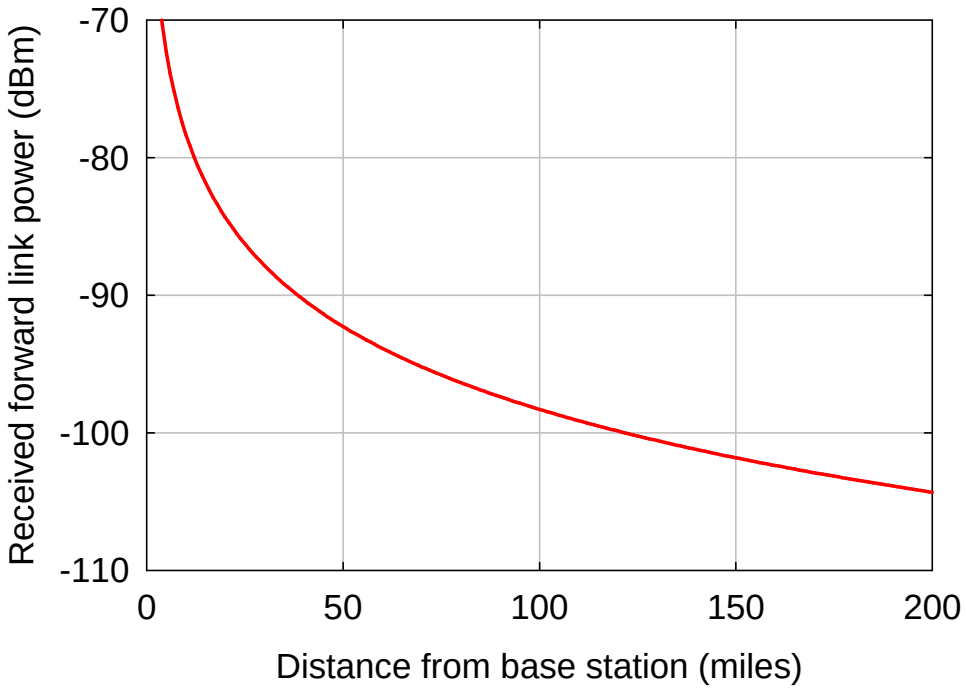
- **AirCell completely ignored base-to-base interference, which does not appear justifiable based on tower-to-tower radio horizons (about 18 to 44 miles).**
- **AirCell's assessment of the minimal impact of aircraft-to-aircraft interference depends on several optimistic assumptions.**
- **As shown here, interference impact is highly sensitive to the assumed conditions and can be very severe (even neglecting the base-to-base interference).**
- **For true broadband aircraft-to-base services, the aircraft transmit power will likely be higher than assumed here and the interference effects will be correspondingly greater.**
- **From a regulatory perspective, it cannot be assumed that the conditions used for the AirCell analysis will apply.**
- **The cross-duplexed band sharing is therefore not a reliable regulatory vehicle for managing the ATG spectrum.**

Additional Technical Background

The Forward Link

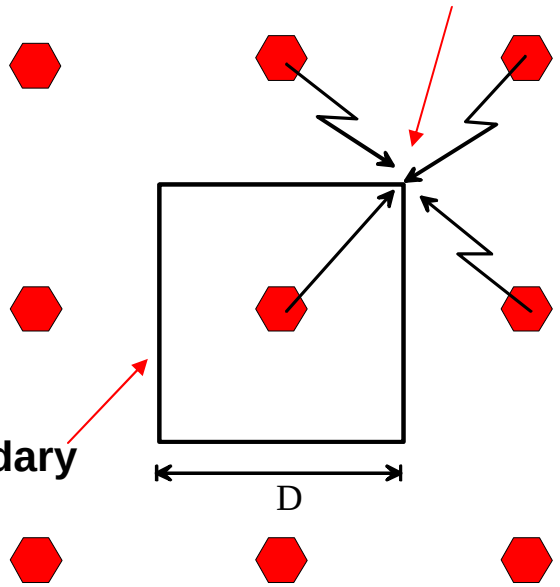
$$P_{RX} = \underbrace{+43}_{\text{PA output}} \underbrace{-3}_{\text{cable}} \underbrace{-2}_{\text{diplexer}} \underbrace{+9}_{\text{antenna gain}} \underbrace{-95.3-20\log d}_{\text{free space loss at 870 MHz}} \underbrace{-M_{sys}}_{\text{system performance margin (10 dB)}}$$

$$= -48.3 - M_{sys} - 20\log d \quad \text{dBm}$$



Square grid layout

SINR ~ –5 dB at corner (ignoring thermal noise)



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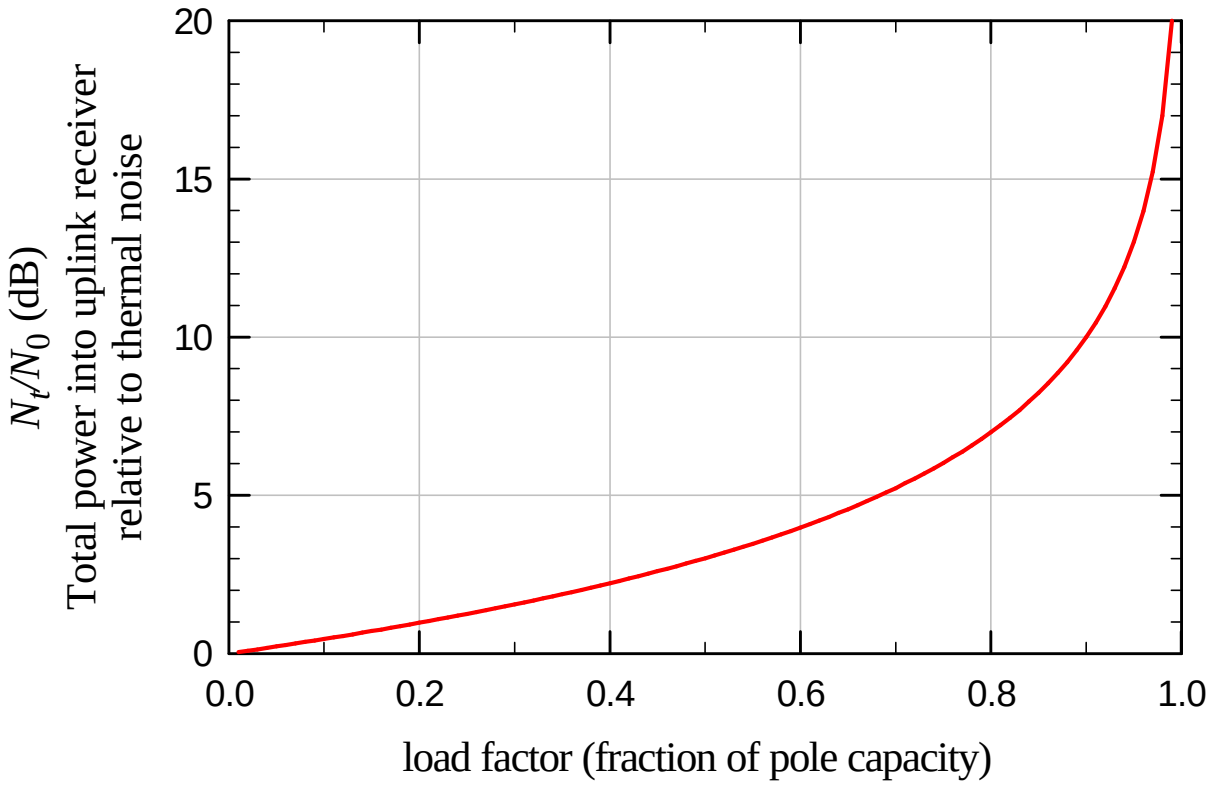
CDMA Reverse Link with Perfect Power Control



Jamming Margin

$$M_J = \frac{W}{R}\left(\frac{E_b}{N_t}\right)_{\text{min}}$$

Required transmit EIRP per 9.6 kb/s speech channel:

$$P_{TX} = \underbrace{-113}_{kTB} \underbrace{+5}_{\text{noise figure}} \underbrace{+6}_{\text{loading (75\%)}} \underbrace{+3}_{\text{cable}} \underbrace{+2}_{\text{dipl.}} \underbrace{-9}_{\text{ant. gain}} - \underbrace{17}_{\text{jamming margin}} + \underbrace{95.3 + 20\log d}_{\text{path loss at 870 MHz (distance in miles)}} + \underbrace{M_{sys}}_{\text{system performance margin}}$$

$$= -27.7 + M_{sys} + 20\log d$$

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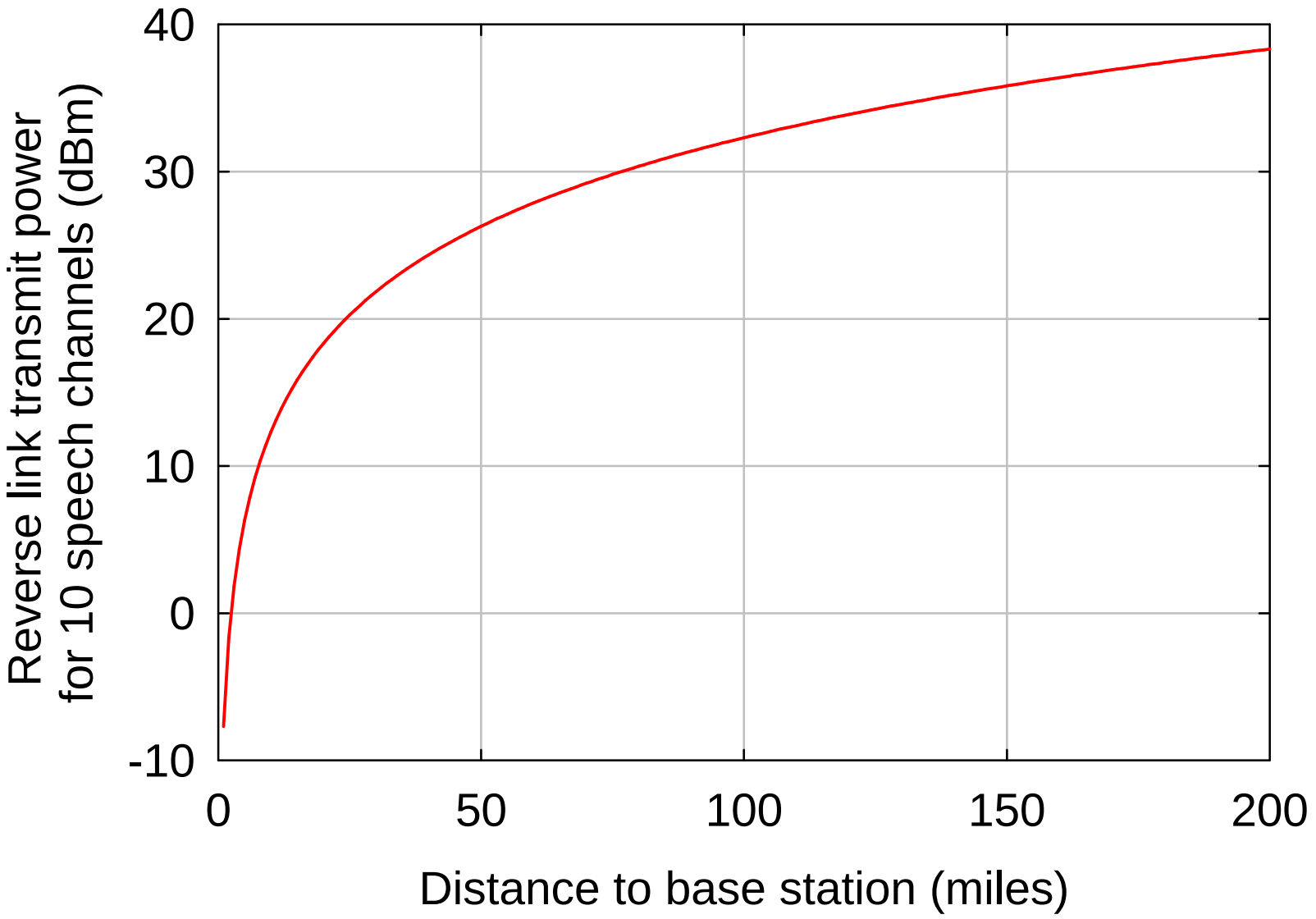
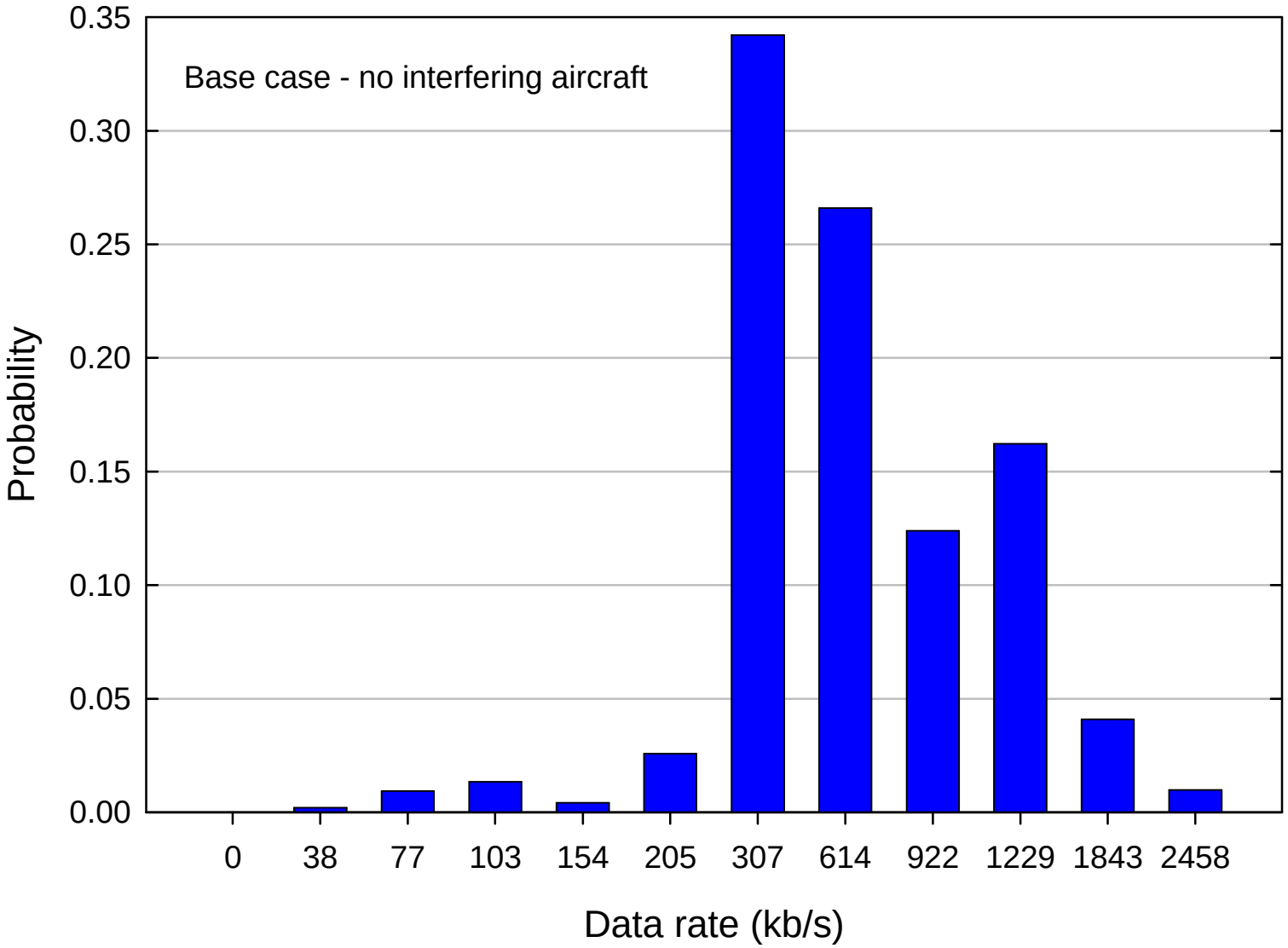
Reverse Link Transmit Power vs. Distance (75% loading)



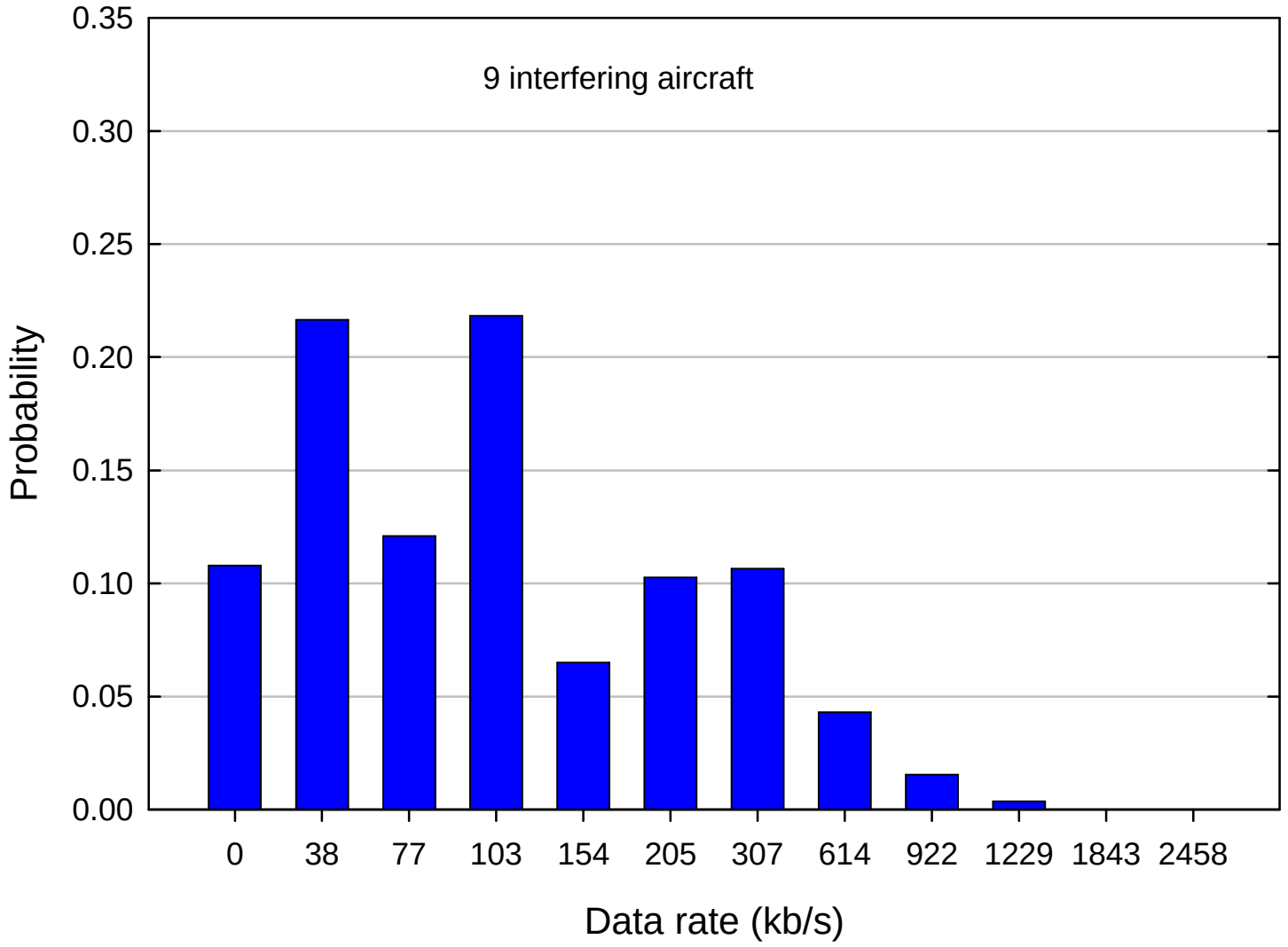
SINR at the Cell Corners

- **D = 200 miles (side of the square).**
- **Victim and interfering aircraft 140 miles from their bases.**
- **10 dB system performance margin for all paths.**
- **Aircraft EIRP = 35 dBm (10 transmitting voice circuits), received interference (5 mile separation, giving 109 dB path loss) is –74 dBm.**
- **Received power from desired and each of 3 interfering base stations is –101 dBm.**
- **SINR is roughly – 27 dB, which is an outage with 1xEvDO (a minimum SINR of –12.5 dB is required for the lowest rate).**
- **Without the other aircraft, the SINR is about –5 dB (3 interfering base stations, all at the same level as the desired signal, plus some noise).**
- **The SINR without interference (–5 dB) can support a rate of 153.6 kb/s.**

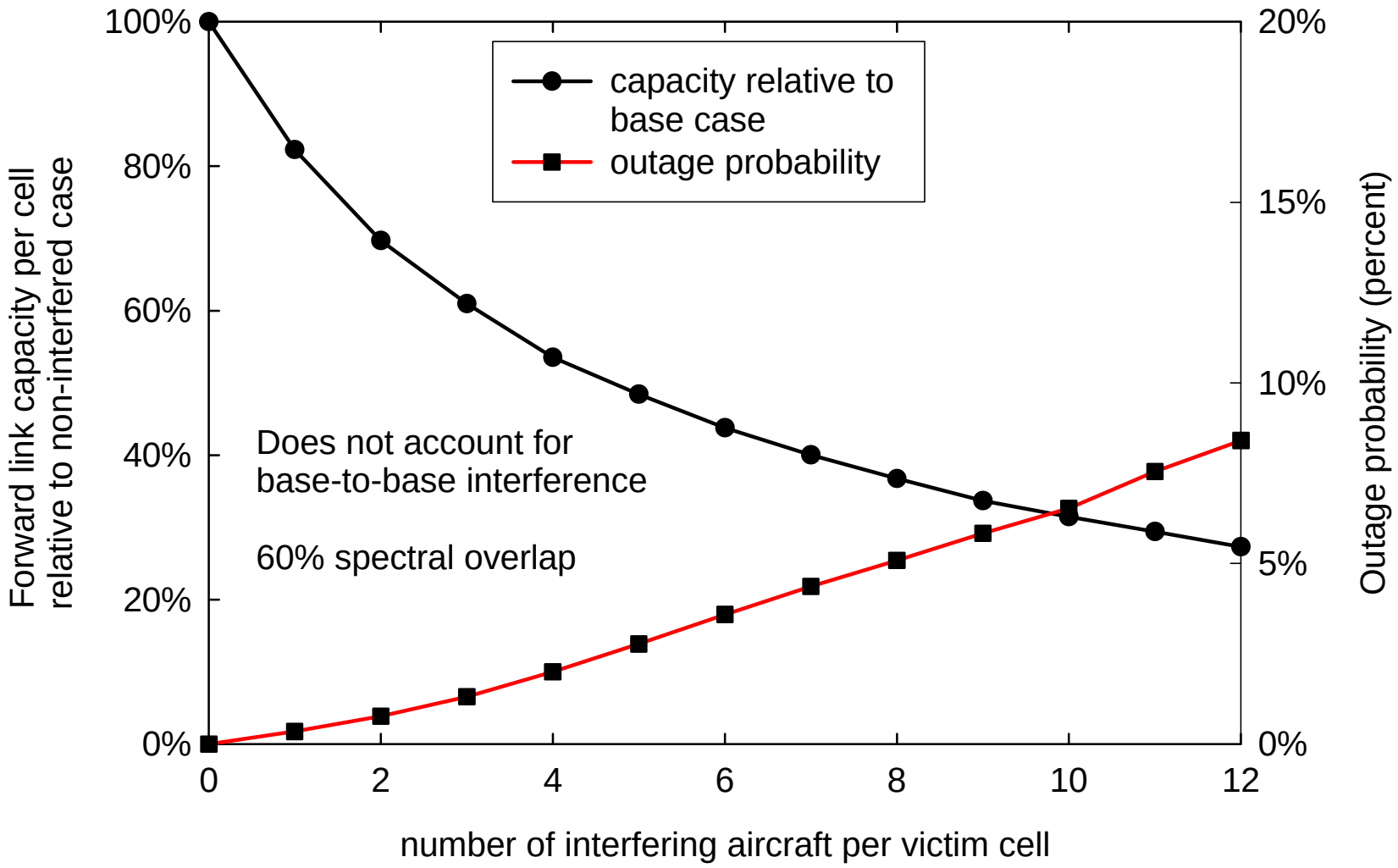
Data Rate Distribution – no Cross-Duplex Interference



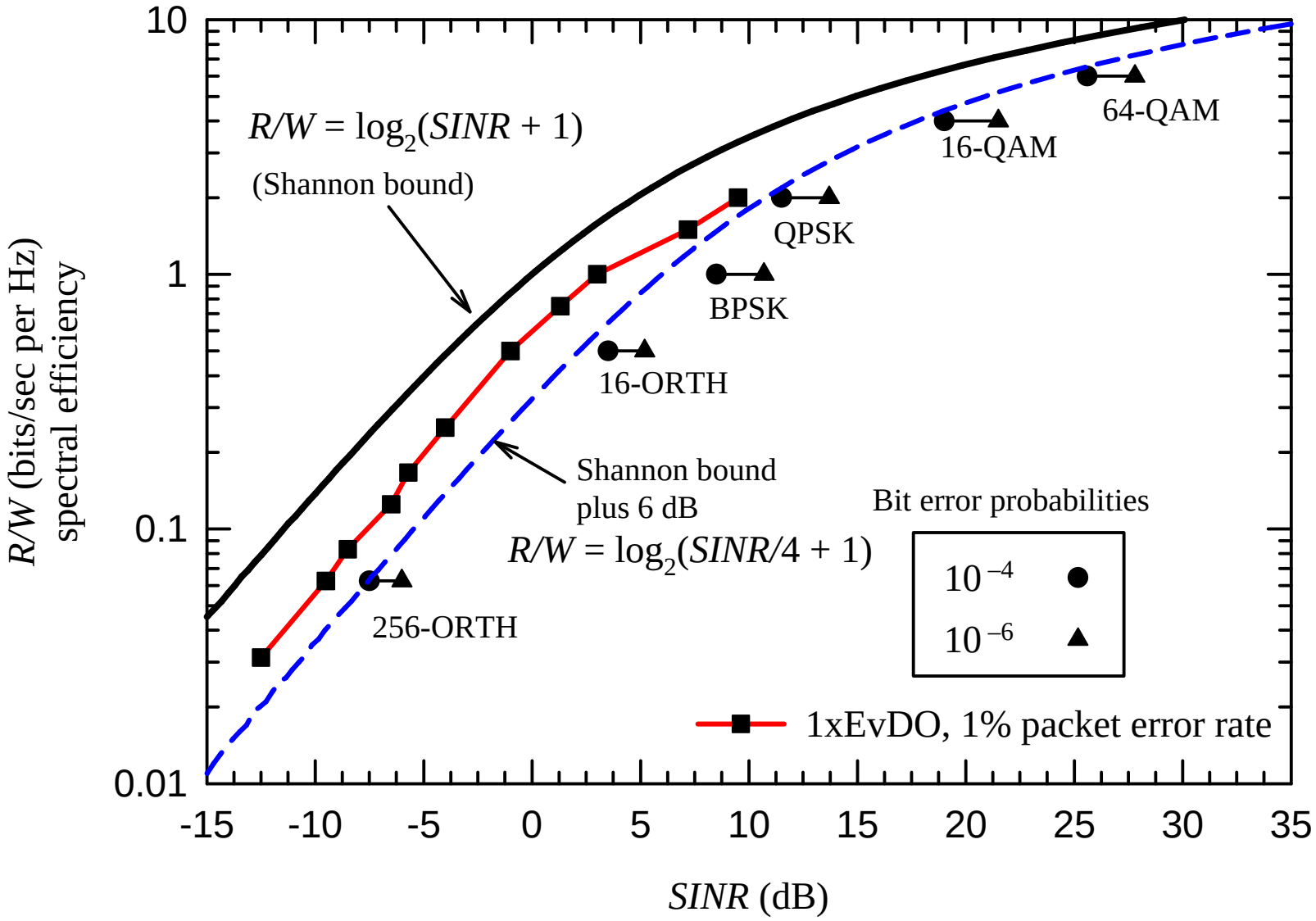
Data Rate Distribution – 9 Aircraft/cell (75% Loading at 3 sectors/cell) and 100% spectral overlap



Simulation Results with 60% Spectral Overlap



Rate vs. SINR


10
1
0.1
0.01
-15
-10
-5
0
5
10
15
20
25
30
35
R/W (bits/sec per Hz)
spectral efficiency
SINR (dB)
R/W = log2(SINR + 1)
(Shannon bound)
64-QAM
16-QAM
QPSK
BPSK
16-ORTH
Shannon bound
plus 6 dB
R/W = log2(SINR/4 + 1)
256-ORTH
Bit error probabilities
10 −4
10 −6
1xEvDO, 1% packet error rate