802.16e Proposal: Link Performance of WirelessMAN-SCa Mobile Subscriber Stations

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Base Document:

"Call for Proposals on IEEE Project 802.16e: Mobility Enhancements to IEEE Standard 802.16/802.16a", IEEE 802.16e-03/02, 2003-01-16, and "Mobile System and Proposal Evaluation Requirements", IEEE 802.16e-03/01, 2003-01-16.

Purpose:

To establish the utility and limitations of the existing 802.16-SCa physical layer specification toward meeting the requirements of the IEEE Project 802.16e.

Link Performance of WirelessMAN-SCa Mobile Subscriber Stations

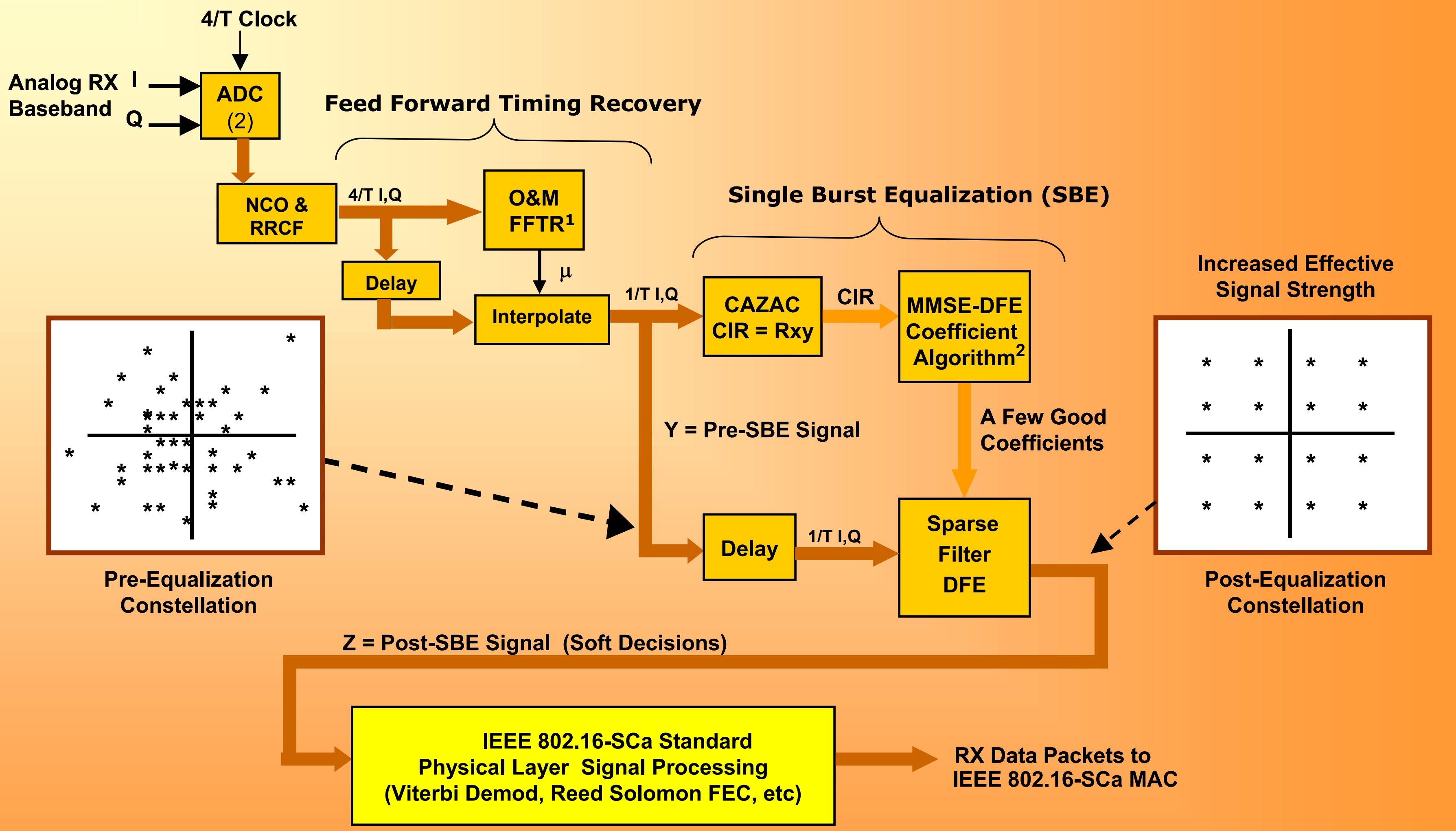
- Single Burst Equalization Overview
- WirelessMAN-SCa Mobility Design Concepts
- Link Simulation Results
- Uplink/Downlink Cell Radii
- Conclusions
- Uplink/Downlink Budgets for Cell Radii

Single Burst Equalization (SBE)

- SBE Baseband Architecture
  - Timing recovery (non data aided, feed forward, after delay)
  - Channel impulse response (CIR) estimation (Unique Word Preamble)
  - Coefficient computation for equalization filters (Al-Dhahir & Cioffi, 1995)
  - FFE & FBE filter coefficient selection (from 64 or 256 to less than ~12, each) [1]
  - Sparse filter DFE execution (after delay for the coefficients) [1]
- SBE Performance
  - Near optimal RX with no a priori of channel
  - Robust and efficient
  - Solves problem of multipath spectral nulls
- SBE Cycle Time Requirement
  - Derived for fixed WirelessMAN-SCa base stations
  - Real time for sequential shortest bursts (BW-REQ), multipoint-to-point
  - ~47 microseconds for 10 MHz BW / 8 MSps

[1] FFE = feed forward equalization, FBE = feed back equalization, DFE = decision feedback equalizer.

SBE Baseband Architecture (Pre-processor)

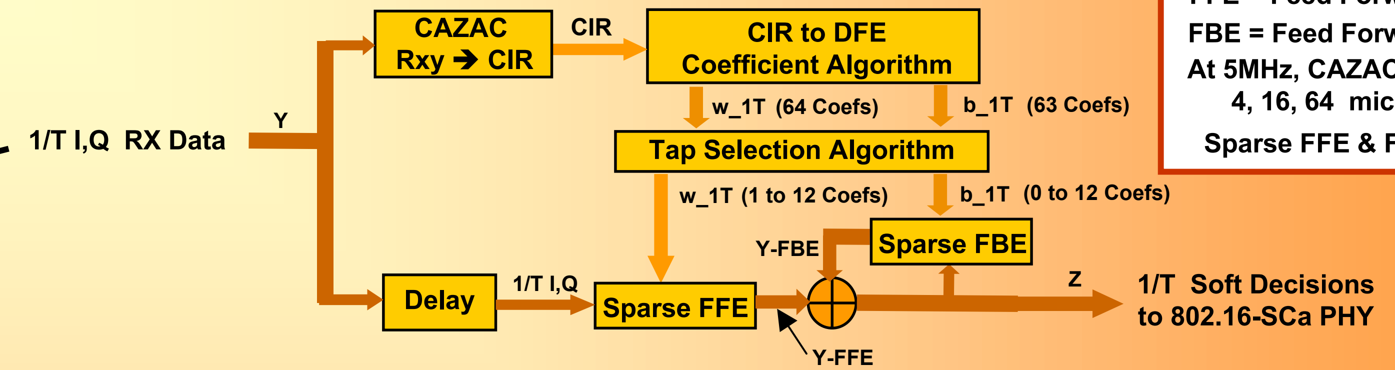


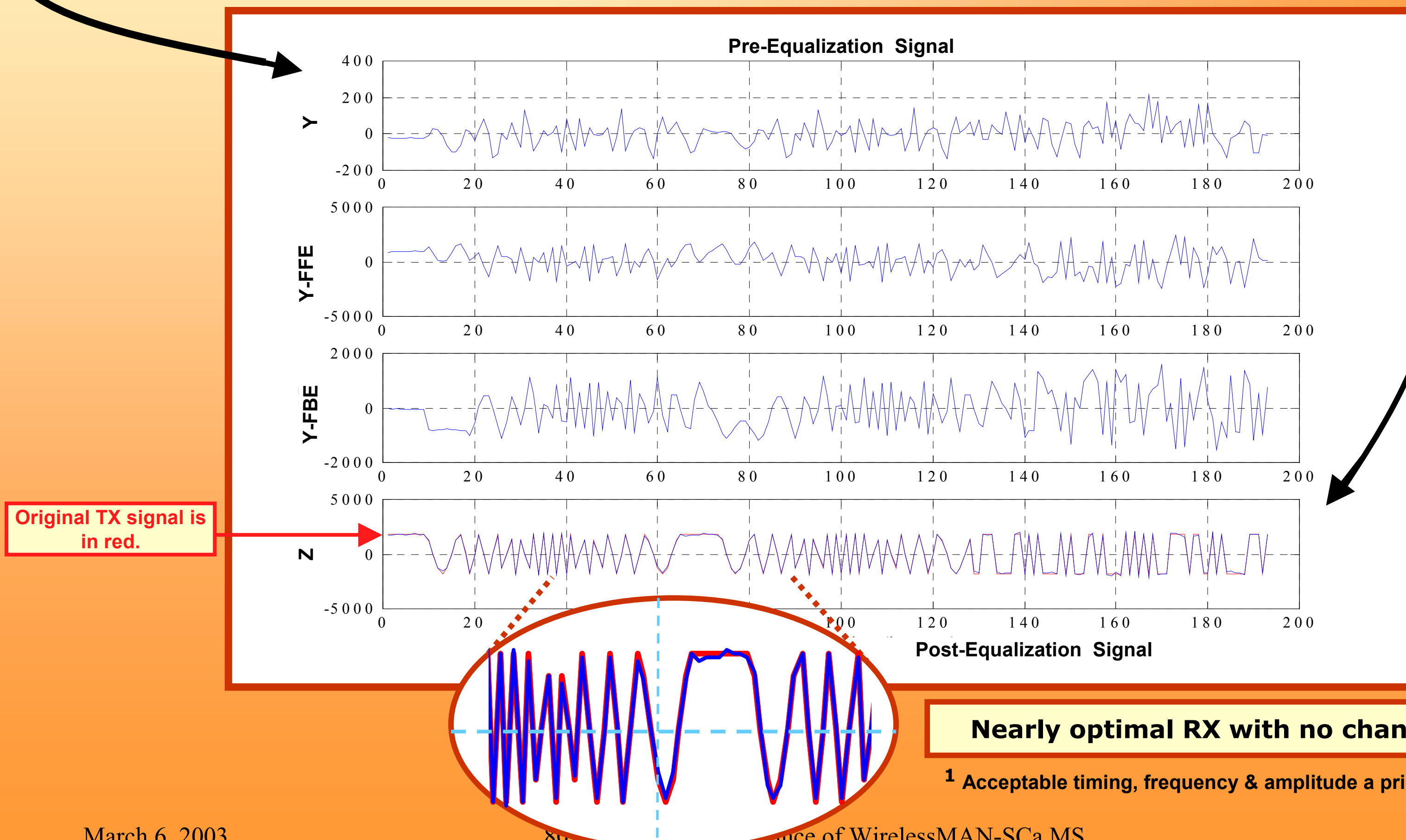
[1] M.Oerder and H. Meyr, "Digital Filter and Square Timing Recovery", IEEE Trans. Commun. COM-36, 605-611, May 1988

[2] Naofal Al-Dhahir & John M. Cioffi, "Fast Computation of Channel-Estimate Based Equalizers in Packet Data Transmissions" in IEEE Transactions on Signal Processing. pp. 2462-2473, 11, 43 (Nov. 1995).

SBE is robust and efficient

FFE = Feed Forward Equalization (filter)
FBE = Feed Forward Equalization (filter)
At 5MHz, CAZAC/CIR/DFE Configures for 4, 16, 64 microsecond delay spread
Sparse FFE & FBE < ~12 Coefficients

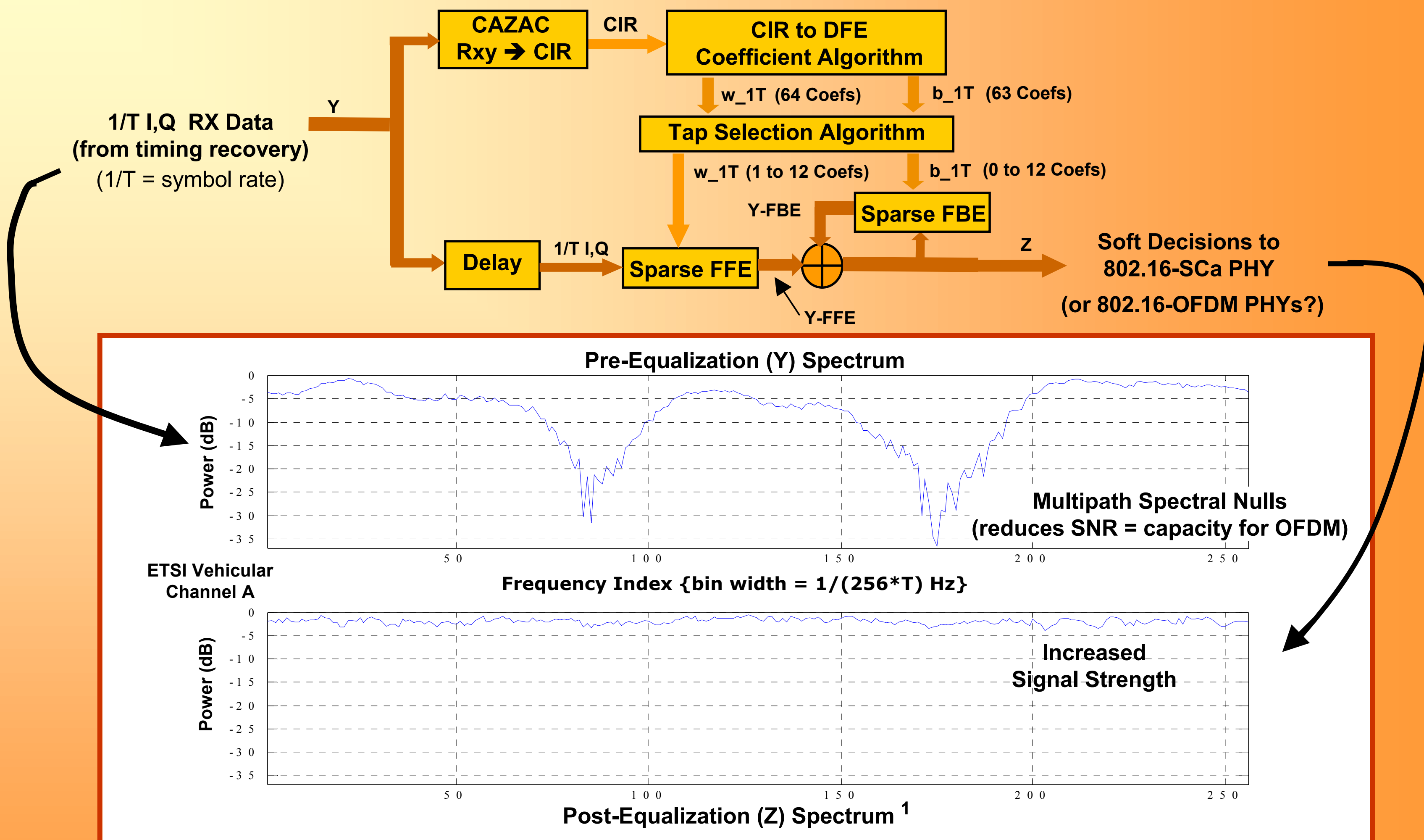




Nearly optimal RX with no channel a priori.[1]

[1] Acceptable timing, frequency & amplitude a priori (CAZAC recovery).

SBE solves the problem of multipath spectral nulls



[1] Spectrum = power spectral density obtained using 512 FFT for dual 256 CAZAC preamble, keeping only the odd index bins.

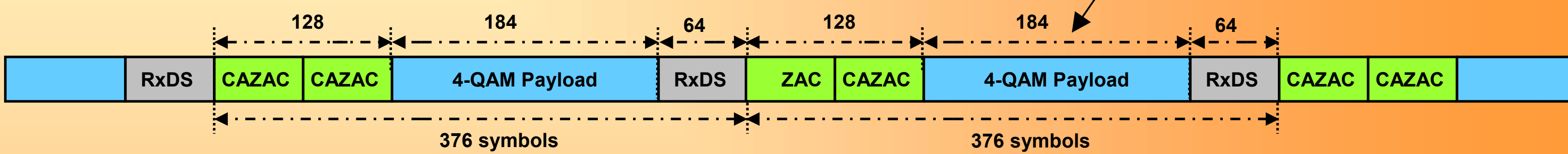
SBE Cycle time for WirelessMAN-SCa FBWA BS

Stay real time while receiving string of shortest SS bursts.

Bandwidth Request Message Bursts [with dual Unique Word Preamble to estimate CIR] :

Unique Word = 64 symbol CAZAC

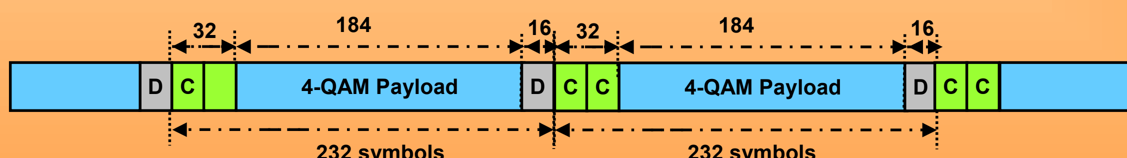
184 Symbol Payload = 8 symbols (Viterbi)
+ (1 symbol per bit)*(6 byte PDU + 16 byte RS)*(8 bits per byte)



376 microseconds for 1.25 MHz BW, 1 MSPS
94 microseconds for 5 MHz BW, 4 MSPS
47 microseconds for 10 MHz BW, 8 MSPS
23.5 microseconds for 20 MHz BW, 16 MSPS

} **SBE Cycle Time Requirement Drivers**

Unique Word = 16 symbol CAZAC



232 microseconds for 1.25 MHz BW, 1 MSPS
58 microseconds for 5 MHz BW, 4 MSPS
29 microseconds for 10 MHz BW, 8 MSPS
14.5 microseconds for 20 MHz BW, 16 MSPS

} **Not Requirement Drivers[1]**

[1] The SBE coefficient compute time for 64 symbol CAZAC is ~16 times the SBE coefficient compute time for 16 symbol CAZAC.

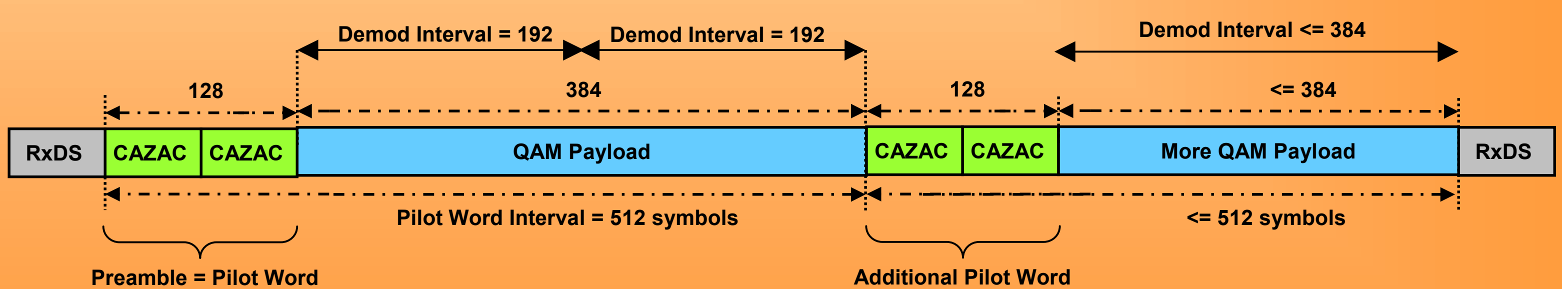
WirelessMAN-SCa Mobility Design Concepts

- 802.16e Base stations (BS) use real time SBE (same as 802.16a)
- 802.16e Mobile subscriber stations (MS) use real time SBE
- Fixed subscriber stations (SS) use whatever (not critical)
- MAC inserts additional Pilot Words on MS/BS links
  - Uses existing Pilot Word insertion protocol
  - Not required for 3 kph pedestrian
  - Not required for short bursts
  - As required to mitigate vehicular Doppler
  - SBE simulations → recommended Pilot Word Insertion Intervals
- BS ranges MS with unsolicited RNG-RESP (as necessary)
  - BS measures ranging parameters on each RX burst
  - Issues RNG-RESP to keep MS within tolerance

802.16-SCa PHY Mobility Design Concept

- Both BS & MS use SBE
  - Estimate CIR from Preamble = Pilot Word = 2 Unique Words
    (UW =64 CAZAC, nominally)
  - Compute (64) FFE & (63) FBE coefficients ("MMSE-DFE" algorithm)
  - Tap selection algorithm ➔ sparse FFE/FBE filters in DFE
- MAC inserts additional Pilot Words based on link statistics
  - None for short bursts (BWREQ, RNG-REQ)
  - At currently allowed intervals, as required, for longer bursts
  - PHY uses Pilot Words to re-compute CIR and FFE/FBE coefficients
  - PHY DFE uses nearest (or interpolated in symbol time) FFE/FBE coefficients

(let "Demod Interval" = maximum symbol distance from Pilot Word[1])



[1] **The performance of the SBE enabled MS & BS depends on the product of Doppler (Hz) times Demod Interval (seconds).**

802.16-SCa PHY Mobility Design Concept (cont.)

- MAC inserts additional Pilot Words based on link statistics
  - **At currently (802.16-SCa) allowed intervals, as required, for longer bursts**
    - **PW insertion interval depends on link BW & SNR/Mod** (below)
    - **Decrease/increase interval based on link errors at SNR/Mod**
    - **Minimum PW interval = 2048/16 = 1024/8 = 512/4 = 128 microseconds**
      > SBE cycle time = 47 microseconds

Recommended Pilot Word Insertion Interval in symbols.[1]

Velocity (kph)	1.25 MHz BW	5 MHz BW	10 MHz BW	20 MHz BW
< 30	not required	not required	not required	not required
38	4096 (3%) [2]	4096 (3%) [3]	4096 (3%) [4]	4096 (3%) [4]
75	2048 (6%)	2048 (6%)	4096 (3%)	4096 (3%)
150	1024 (11%)	1024 (11%)	2048 (6%)	4096 (3%)
300	512 (20%)	512 (20%)	1024 (11%)	2048 (6%)

Improves link, with acceptable overhead. (↓)

[1] Table is for 9 < Es/No < 21, e.g, QPSK or 16-QAM, for Es/No > 21 dB or 64 QAM divide insertion interval by 2.

[2] Percent overhead = (32/(32+insertion interval))*100% for BW = 1.25 MHz with UW = 16 CAZAC.

[3] Percent overhead = (128/(128+insertion interval))*100% for BW = 5,10, 20 MHz with UW = 64 CAZAC.

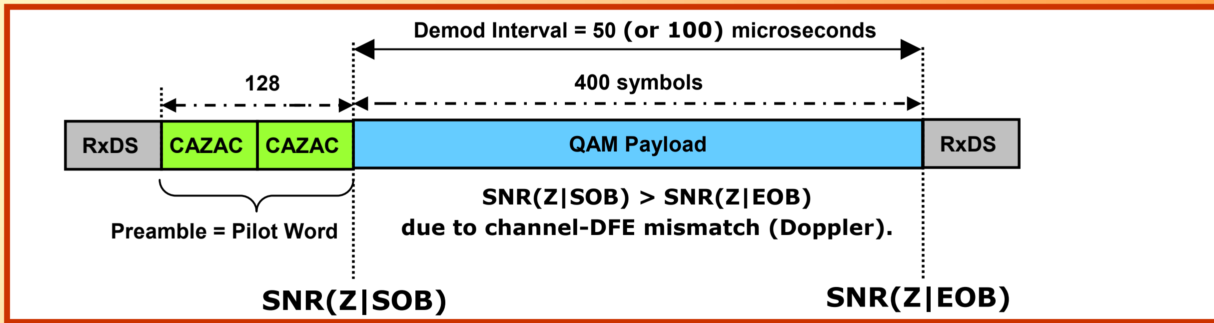
[4] For higher bandwidths (10 & 20 MHz) the symbol rate is faster so the equivalent number of symbols is less sensitive to Doppler. The recommendation is to use the largest PW interval of 4096 if there is any indication of channel impairment with a mobile subscriber. Most bursts are shorter than 4096 symbols.

Link Simulation Results

- SNR(Y), Y = SBE input, shows channel effects
- SNR of Z = SBE output (input to Viterbi demodulator)
  - SNR(Z|SOB), Start Of Burst
  - SNR(Z|EOB), End Of Burst = “Demod Interval”
- Controls (Perfect channel/AWGN/QPSK SER & familiar SUI channels)
- CIRs for ETSI Test Environments
  - Vehicular, Channel A & B
  - Outdoor-to-indoor & Pedestrian, Channel A & B
  - Indoor Office, Channel A & B
- SNR degradation estimates
  - Stationary test CIR wrt perfect channel = SNR(Z|SOB)-Es/No
  - Mobile test CIR wrt stationary test CIR = SNR(Z|EOB) - SNR(Z|SOB)
  - Mobile test CIR wrt perfect channel = SNR(Z|EOB)-Es/No
- Pilot Word Interval Performance Assessment
  - Doppler SNR degradation = SNR(Z|EOB) - SNR(Z|SOB)
  - Degradation versus Velocity (constant PW interval)
  - Degradation versus PW interval (constant velocity)

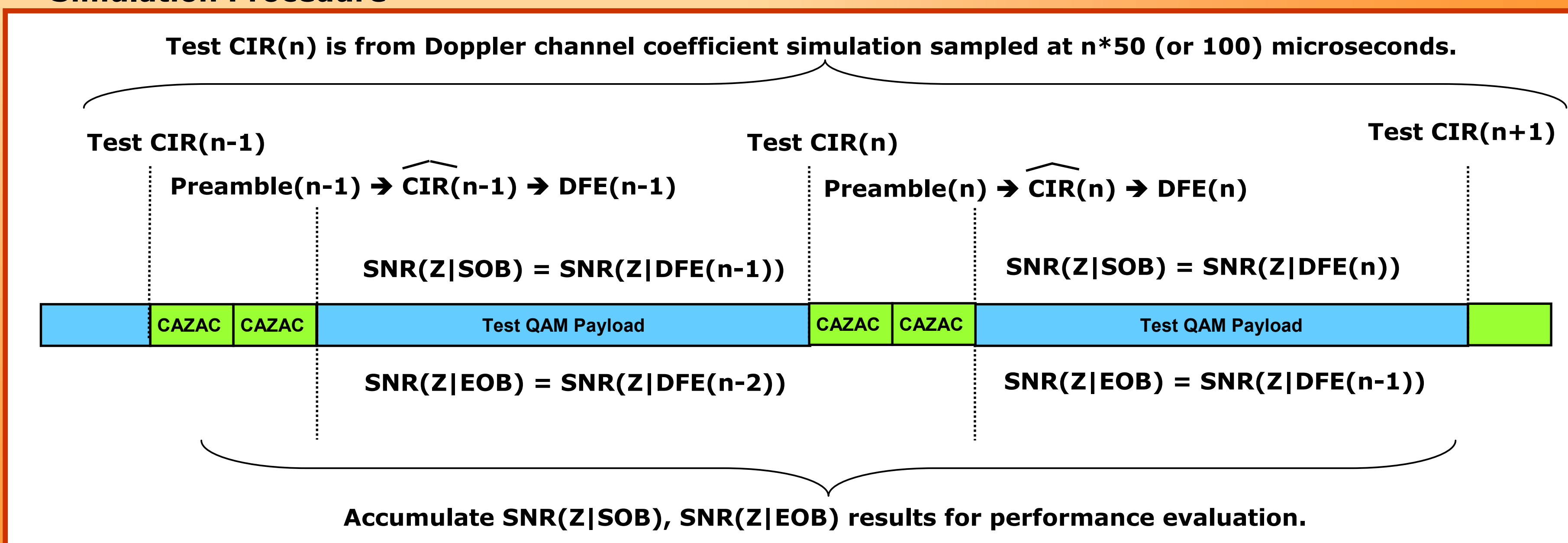
Doppler SNR Degradation = SNR(Z|EOB) – SNR(Z|SOB)

Simulation Concept

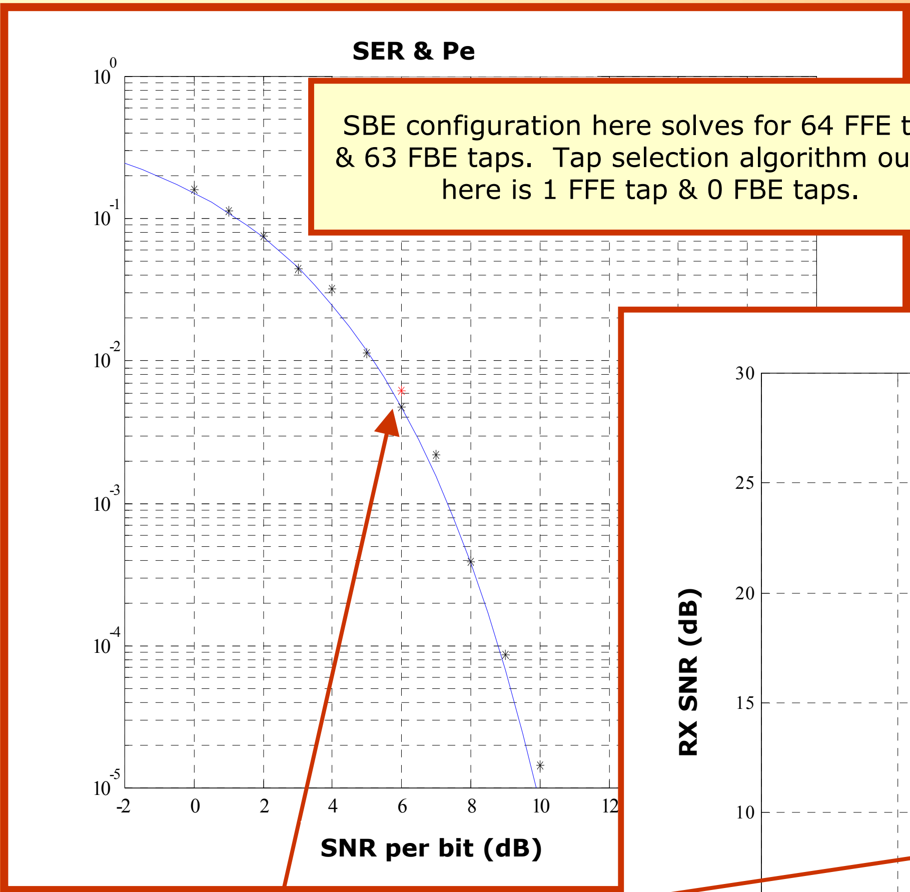


Results are equivalent for constant Doppler*Demod Interval.

Simulation Procedure

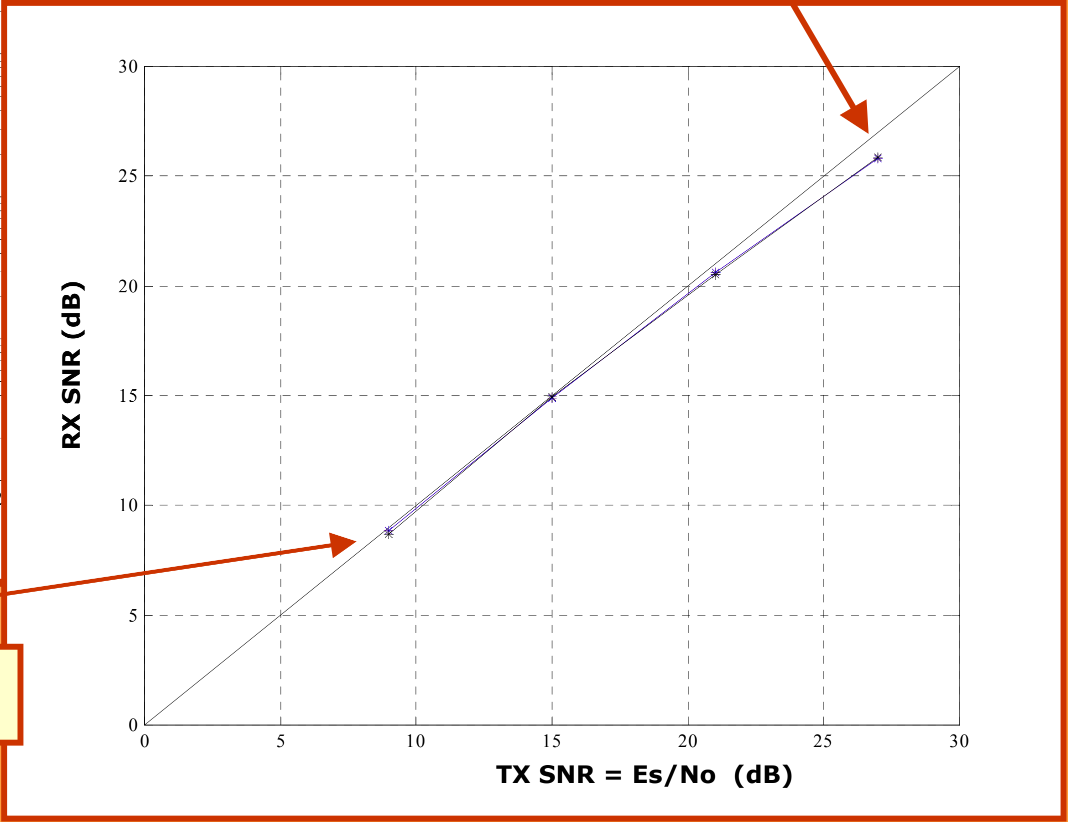


Channel/SBE simulation: perfect channel-AWGN-QPSK control



SBE configuration here solves for 64 FFE taps & 63 FBE taps. Tap selection algorithm output here is 1 FFE tap & 0 FBE taps.

SNR of Y = pre-SBE & Z = SBE-Output fall off from Es/No due to TX/RX filters & arithmetic.

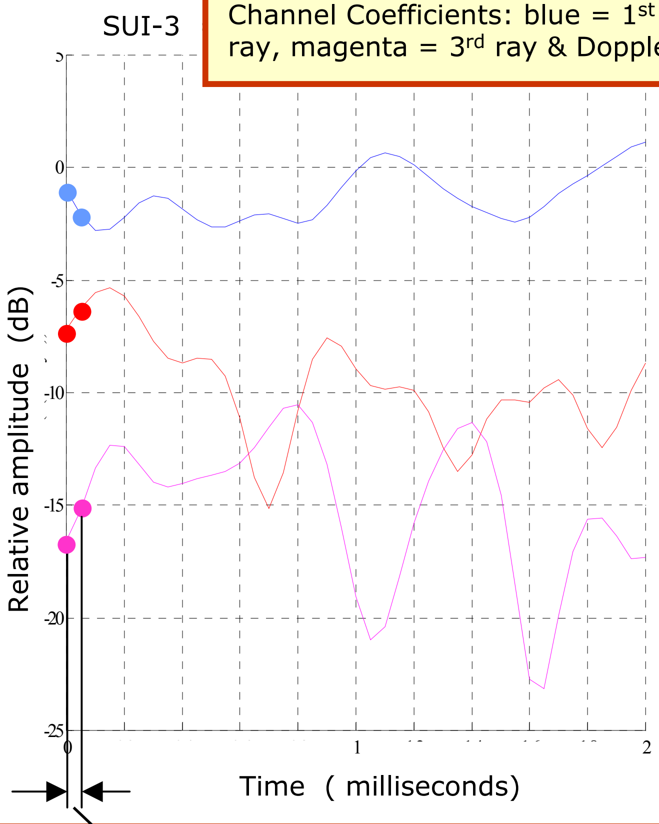


Normally each simulation element is N = 7720 symbol demods at some test configuration.

Channel/ SBE simulation: SUI-3 channel-AWGN-QPSK control

MS velocity = 1500 kph, 5 MHz BW, Demod Interval = 200 symbols = 50 μsec

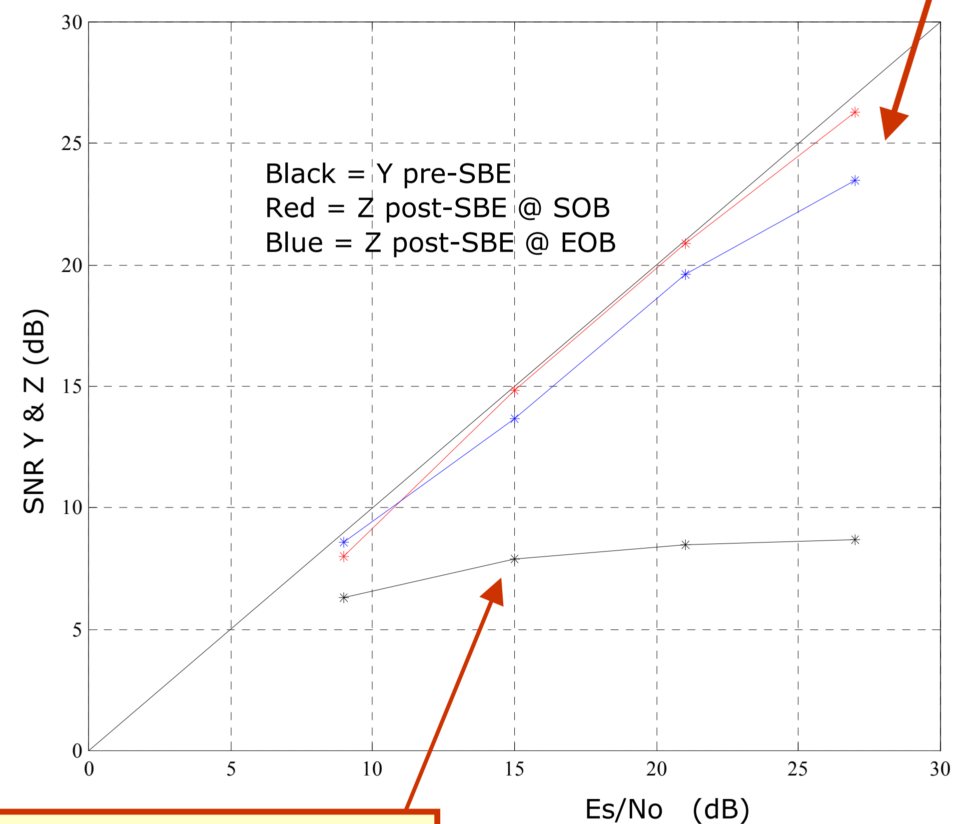
Channel Coefficients: blue = 1st ray, red = 2nd ray, magenta = 3rd ray & Doppler = 3614 Hz.



Demod Interval = 50 μsec

SOB = start of burst
EOB = end of burst (or Demod Interval)

SNR of Z at EOB (blue) falls off from SNR of Z at SOB (red) due to Doppler channel dynamics.



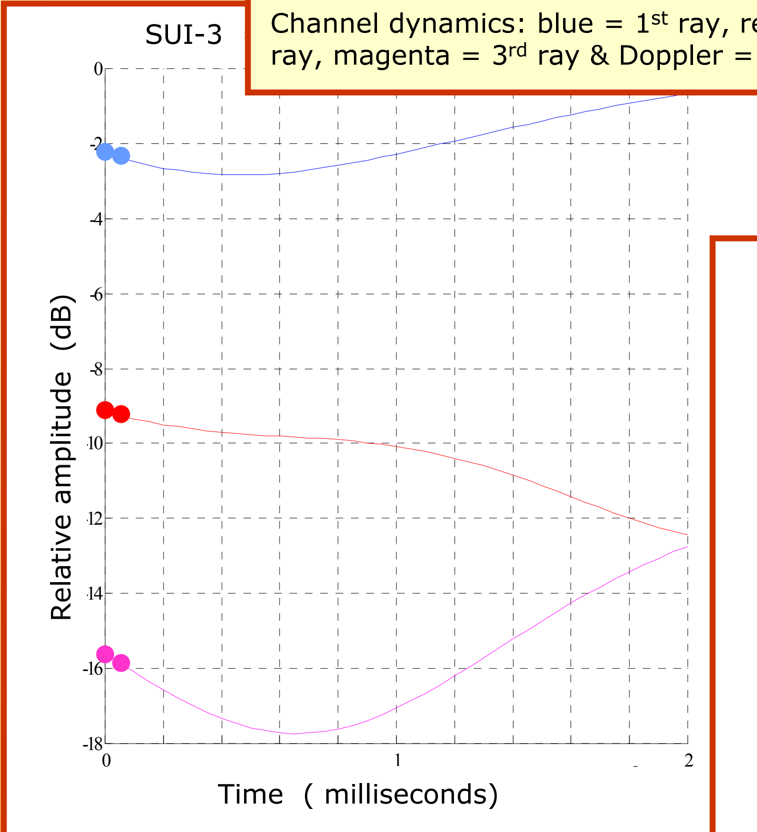
Simulation protocol tested multiple independent random channel realizations (multiple test sets per realization, with each test set generating data at 4 values of Es/No for both SOB & EOB). Arithmetic = 12-bit 2's complement.

SNR of Y is multipath ISI limited.

Channel/ SBE simulation: SUI-3 channel-AWGN-QPSK control

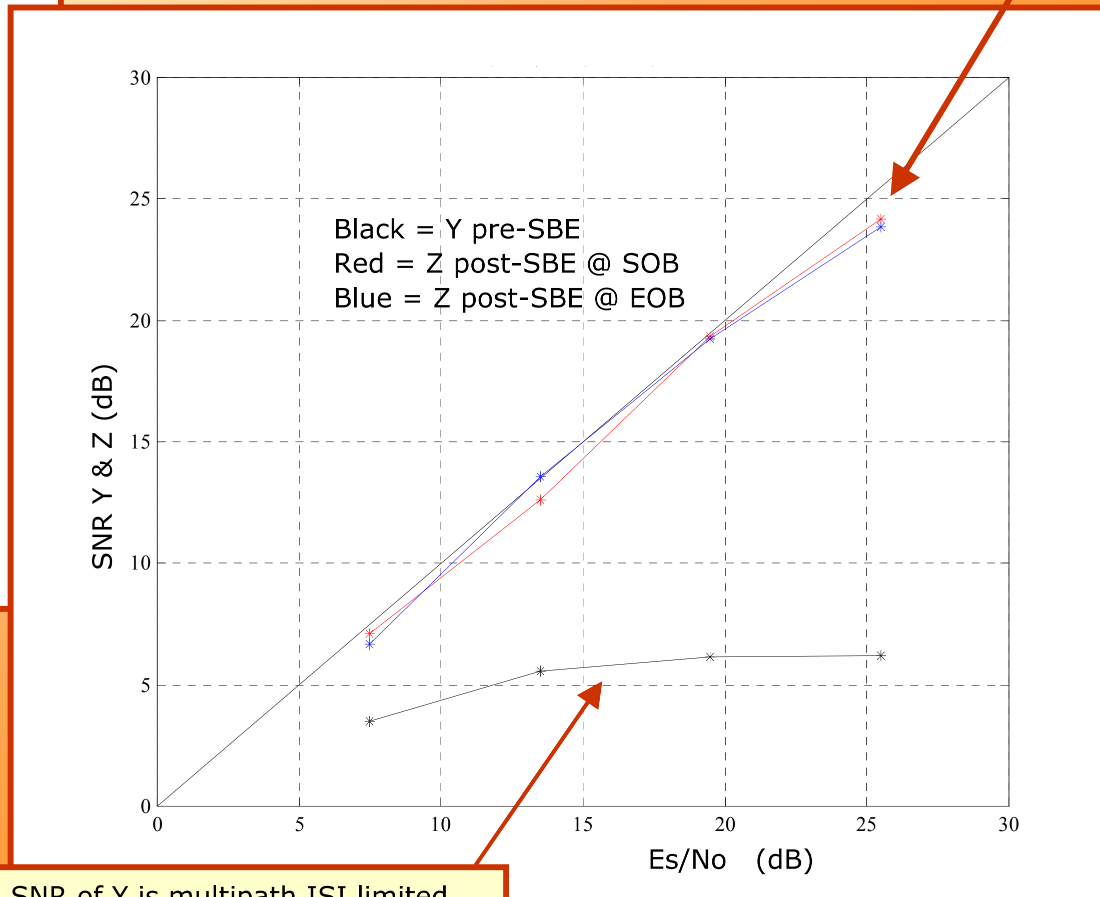
MS velocity = 150 kph, 5 MHz BW, Demod Interval = 200 symbols = 50 μsec

Channel dynamics: blue = 1st ray, red = 2nd ray, magenta = 3rd ray & Doppler = 362 Hz.



SOB = start of burst
EOB = end of burst (or Demod Interval)

SNR of Z at EOB (blue) does not fall off much from SNR of Z at SOB (red) due to Doppler channel dynamics.



Simulation protocol tested multiple independent random channel realizations (multiple test sets per realization, with each test set generating data at 4 values of Es/No for both SOB & EOB). Arithmetic = 12-bit 2's complement.

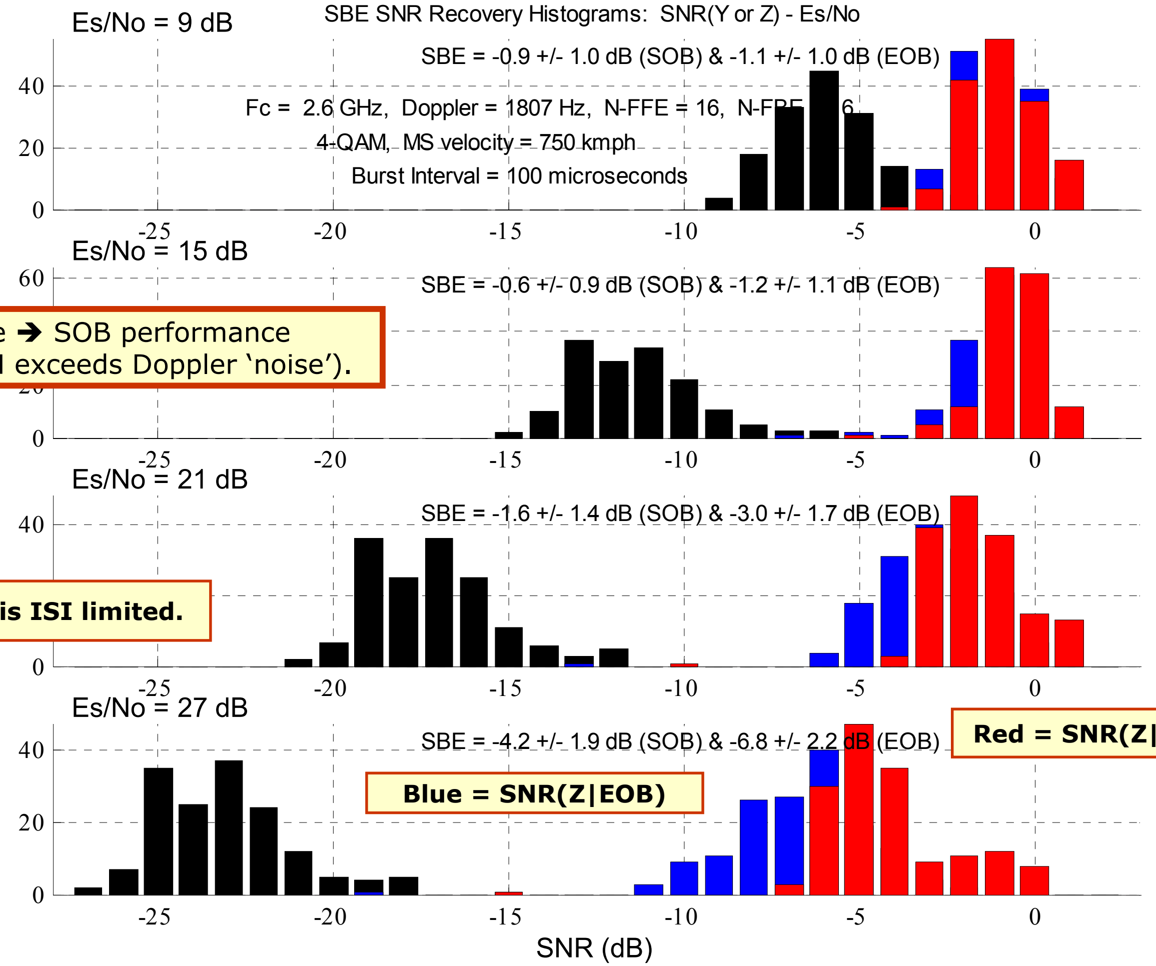
SNR of Y is multipath ISI limited.

Performance Degradation from Perfect Channel, AWGN

SBE for ETSI ITU-R M.1225 Vehicular Test Environment, Channel A
MS velocity = 750 kph , 5 MHz BW, Demod Interval = 400 symbols = 100 μsec

Histograms of SNR(Y or Z) – Es/No show SBE SNR recovery toward Es/No.

Red = SNR(Z|SOB) and Blue = SNR(Z|EOB) do not superimpose due to 3614 Hz Doppler.



EOB performance ➔ SOB performance
for lower Es/No (WGN exceeds Doppler 'noise').

Black = SNR(Y) is ISI limited.

Red = SNR(Z|SOB)

Blue = SNR(Z|EOB)

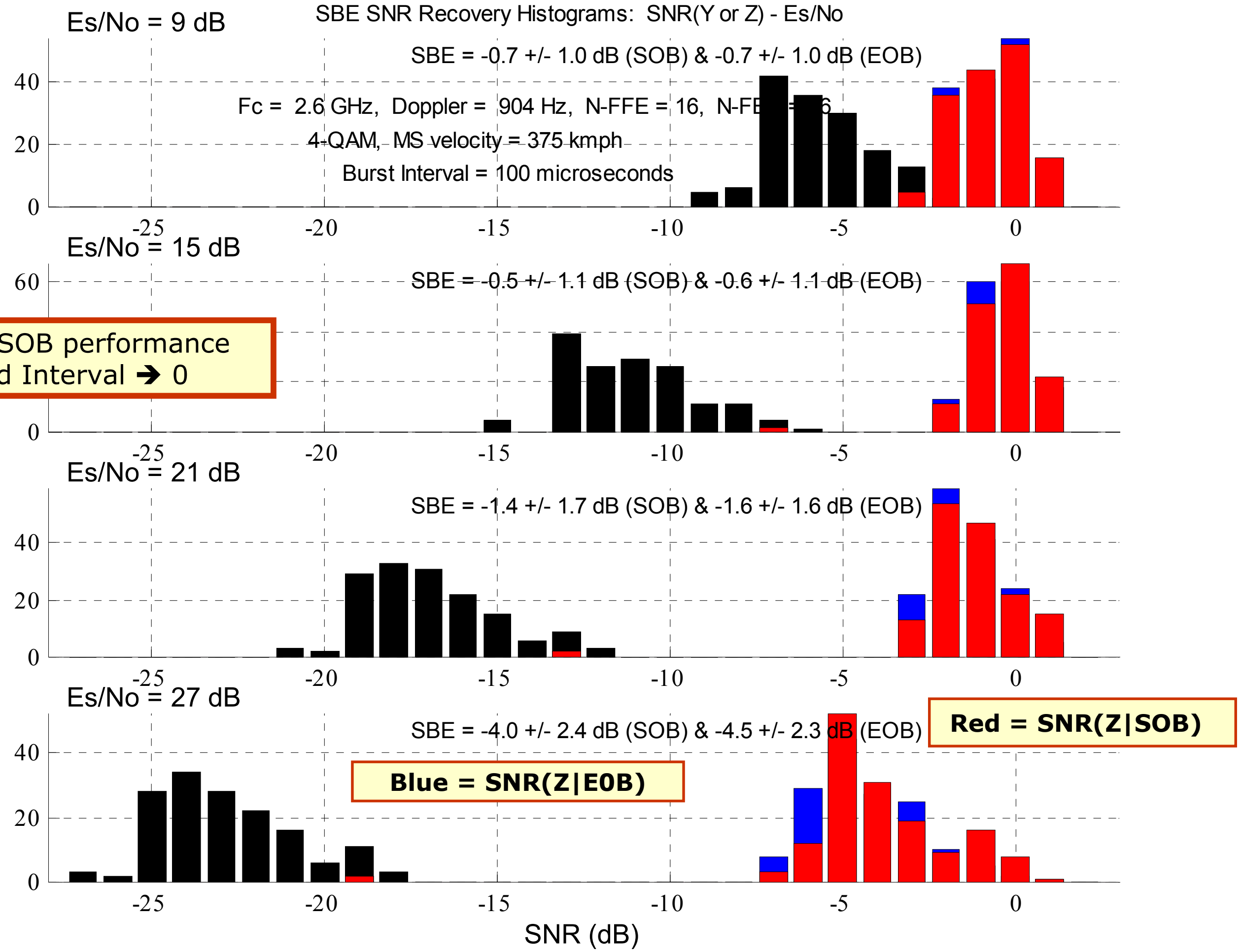
Doppler*Demod Interval = (1807 Hz)*(100 microseconds) = .1807

Performance Degradation from Perfect Channel, AWGN

ETSI ITU-R M.1225 Vehicular Test Environment, Channel A
MS velocity = 375 kph, 5 MHz BW, Demod Interval = 400 symbols = 100 μsec

Histograms of SNR(Y or Z) – Es/No show SBE SNR recovery toward Es/No.

Red = SNR(Z|SOB) and Blue = SNR(Z|EOB) do not superimpose due to 1807 Hz Doppler.



EOB performance ➔ SOB performance as Doppler*Demod Interval ➔ 0

Doppler*Demod Interval = (904 Hz)*(100 microseconds) = .0904

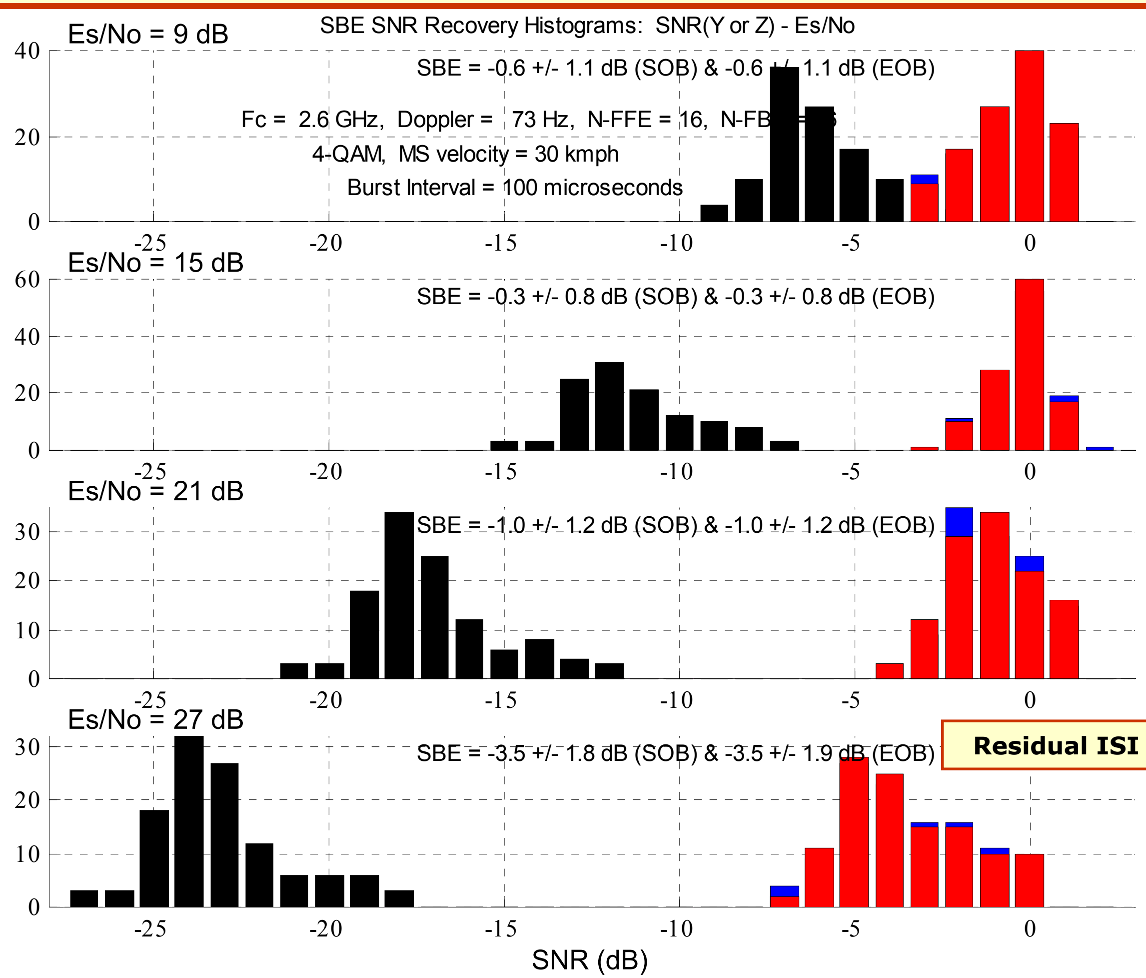
Performance Degradation from Perfect Channel, AWGN

ETSI ITU-R M.1225 Vehicular Test Environment, Channel A

MS velocity = 30 kph, 5 MHz BW, Demod Interval = 400 symbols = 100 μsec

Histograms of SNR(Y or Z) – Es/No show SBE SNR recovery toward Es/No.

Red = SNR(Z|SOB) and Blue = SNR(Z|EOB) superimpose since there is only 73 Hz Doppler.



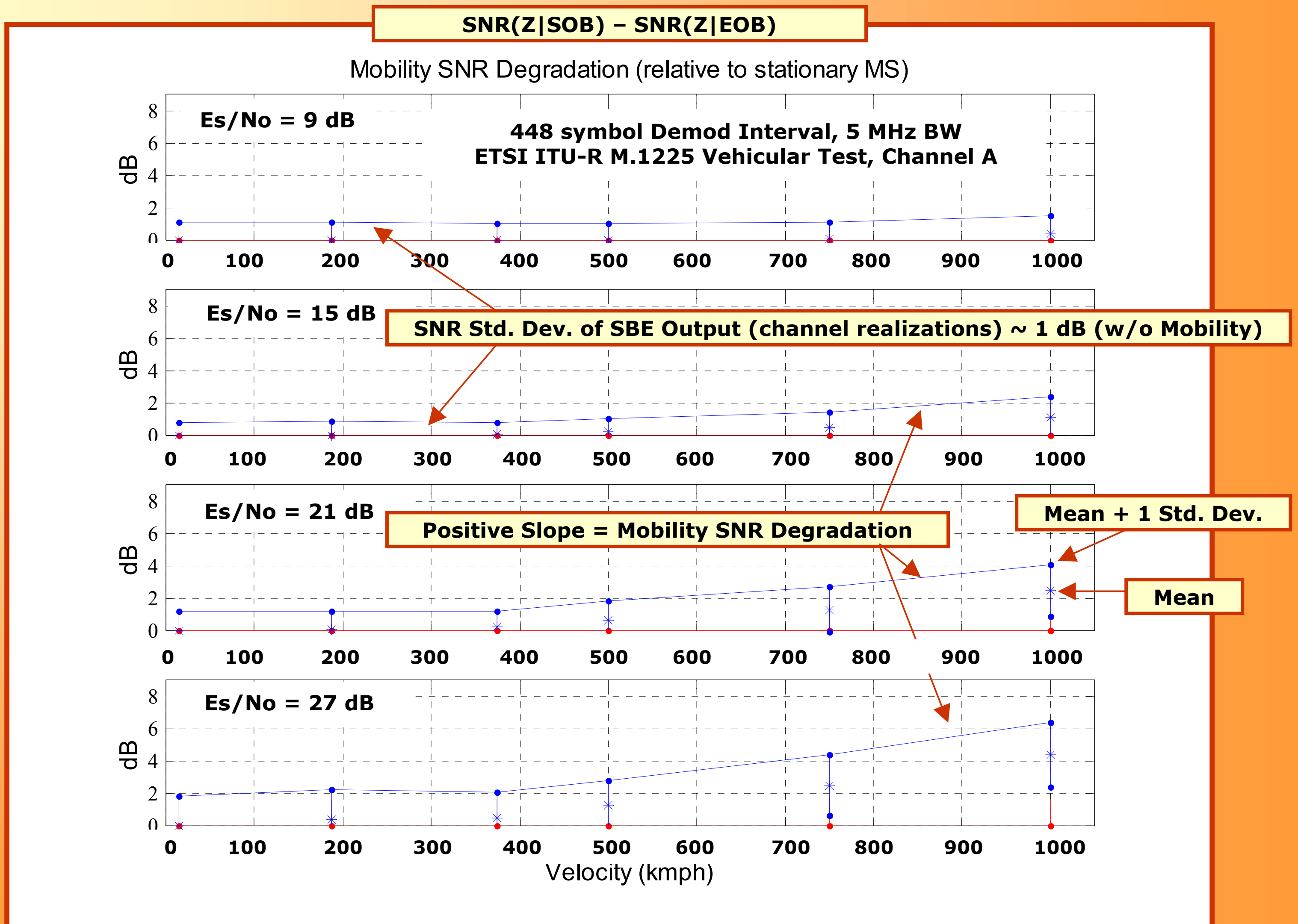
Residual ISI at high Es/No

Doppler* Demod Interval = (73 Hz)*(100 microseconds) = .0073

Mobility SNR Degradation vs Velocity

ETSI ITU-R M.1225 Vehicular Test Environment Channel A

5 MHz BW, PW Interval = 1024 symbols, Demod Interval = 448 symbols

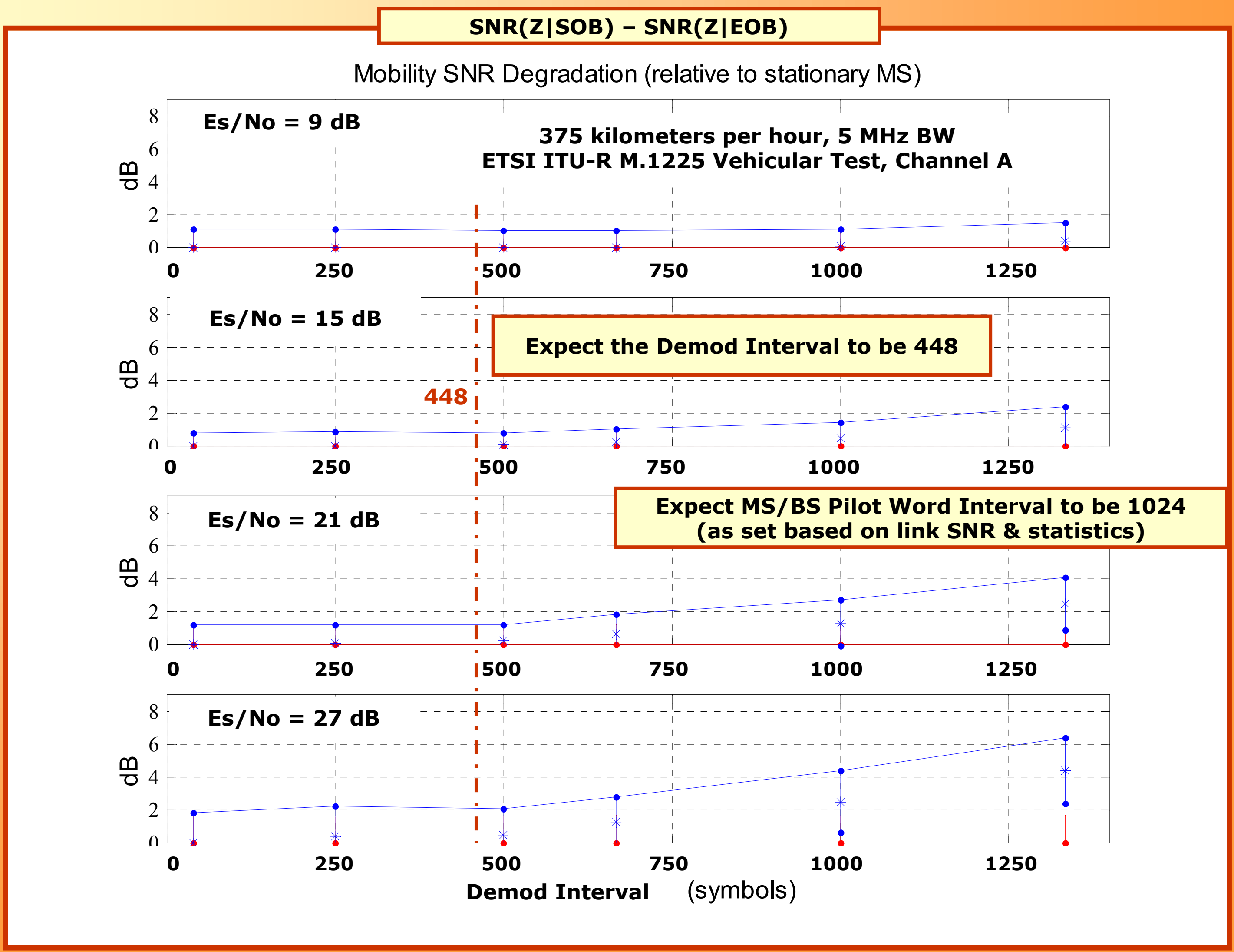


Mobility SNR Degradation vs Demod Interval

ETSI ITU-R M.1225 Vehicular Test Environment Channel A

5 MHz BW, Velocity = 375 kph

SNR(Z|SOB) – SNR(Z|EOB)



MS Performance for WirelessMAN-SCa (PE16)

SBE for ETSI ITU-R M.1225 Vehicular Test Environment, Channel A
5 MHz BW, Demod Interval = 400 symbols = 100 μsec

Mobile MS SNR Delta (relative to stationary MS[1])

Es/No (dB)	<30 kilometers per hour	375 kilometers per hour	750 kilometers per hour
9	0.0 +/- 1.1 dB	0.0 +/- 1.0 dB	-.1 +/- 1.0 dB
15	0.0 +/- .8	.1 +/- .8	-.5 +/- .9
21	0.0 +/- 1.2	-.2 +/- 1.2	-1.3 +/- 1.4
27	0.0 +/- 1.9	-.5 +/- 1.7	-2.5 +/- 1.9

SBE mobile MS performance is typically within 1 dB of stationary MS performance.

[1]Stationary MS or SS SNR delta relative to Es/No (perfect channel, AWGN)

Es/No = 9 dB	Es/No = 15 dB	Es/No = 21 dB	Es/No = 27 dB
-.6 +/- 1.1 dB	-.3 +/- .8 dB [2]	-1.0 +/- 1.2 dB	-3.5 +/- 1.8 dB [3]

SBE multipath performance for Vehicular Channel A is typically within 1 dB of perfect channel performance.

[2] SBE at Es/No = 15 dB is better than at Es/No = 9 dB due to improved CIR estimate (and residual ISI < No).

[3] SBE performance at Es/No = 27 dB shows residual ISI in addition to ~1.5 dB fall off due to TX/RX filters, etc.

MS Performance for WirelessMAN-SCa (PE16)

SBE for ETSI ITU-R M.1225 Vehicular Test Environment, Channel B
5 MHz BW, Demod Interval = 400 symbols = 100 μsec

Mobile MS SNR Delta (relative to stationary MS[1])

Es/No (dB)	<30 kilometers per hour	375 kilometers per hour	750 kilometers per hour
9	0.0 +/- .7 dB	-0.1 +/- .6 dB	0.0 +/- .7 dB
15	0.0 +/- .8	-0.1 +/- .8	-.4 +/- .9
21	0.0 +/- 1.5	-.4 +/- 1.4	-.7 +/- 1.5
27	0.0 +/- 2.1	-.6 +/- 2.1	-1.8 +/- 2.3

SBE mobile MS performance is typically within 1 dB of stationary MS performance.

[1]Stationary MS or SS SNR delta relative to Es/No (perfect channel, AWGN)

Es/No = 9 dB	Es/No = 15 dB	Es/No = 21 dB	Es/No = 27 dB
-.9 +/- .8 dB	-.9 +/- .8 dB	-2.2 +/- 1.4 dB	-5.0 +/- 2.1 dB [2]

SBE multipath performance for Vehicular Channel B is typically within ~2 dB of perfect channel performance.

SBE multipath performance for Vehicular Channel B is typically within 1 dB of Vehicular Channel A performance.

[2] SBE performance at Es/No = 27 dB shows residual ISI in addition to ~1.5 dB fall off due to TX/RX filters, etc.

MS Performance for WirelessMAN-SCa (PE15)

SBE for ETSI ITU-R M.1225 Outdoor-to-Indoor & Pedestrian, Channel A & B
5 MHz BW

SNR Delta relative to Es/No (perfect channel, AWGN)

Es/No (dB)	3 kilometers per hour Channel A	3 kilometers per hour Channel B
9	-.1 +/- .4 dB	-1.4 +/- .7 dB
15	-1.2 +/- .7	-0.6 +/- .7 [1]
21	-2.9 +/- .8	-1.4 +/- 1.0
27	-4.1 +/- 1.3	-3.2 +/- 1.2 [2]

[1] SBE at Es/No = 15 dB is better than at Es/No = 9 dB due to improved CIR estimate (and residual ISI < No).

[2] SBE performance at Es/No = 27 dB shows residual ISI in addition to ~1.5 dB fall off due to TX/RX filters, etc.

SBE 3 kph pedestrian MS performance is equal to the SBE stationary MS performance.

SBE multipath performance for Out-In Ped Channel A/B is typically within 2 dB of perfect channel.

MS Performance for WirelessMAN-SCa (PE15)
SBE for ETSI ITU-R M.1225 Indoor Office, Channel A & B

SNR Delta relative to Es/No (perfect channel, AWGN)

Es/No (dB)	30 kilometers per hour Channel A	30 kilometers per hour Channel B
9	0.0 +/- 1.3 dB	-.7 +/- 1.8 dB
15	0.0 +/- 1.7	- 1.4 +/- 1.5
21	-1.9 +/- 2.4	-2.9 +/- 1.7
27	-4.9 +/- 3.5 [1]	-5.4 +/- 2.8 [1]

[1] SBE performance at Es/No = 27 dB shows residual ISI in addition to ~1.5 dB fall off due to TX/RX filters, etc.

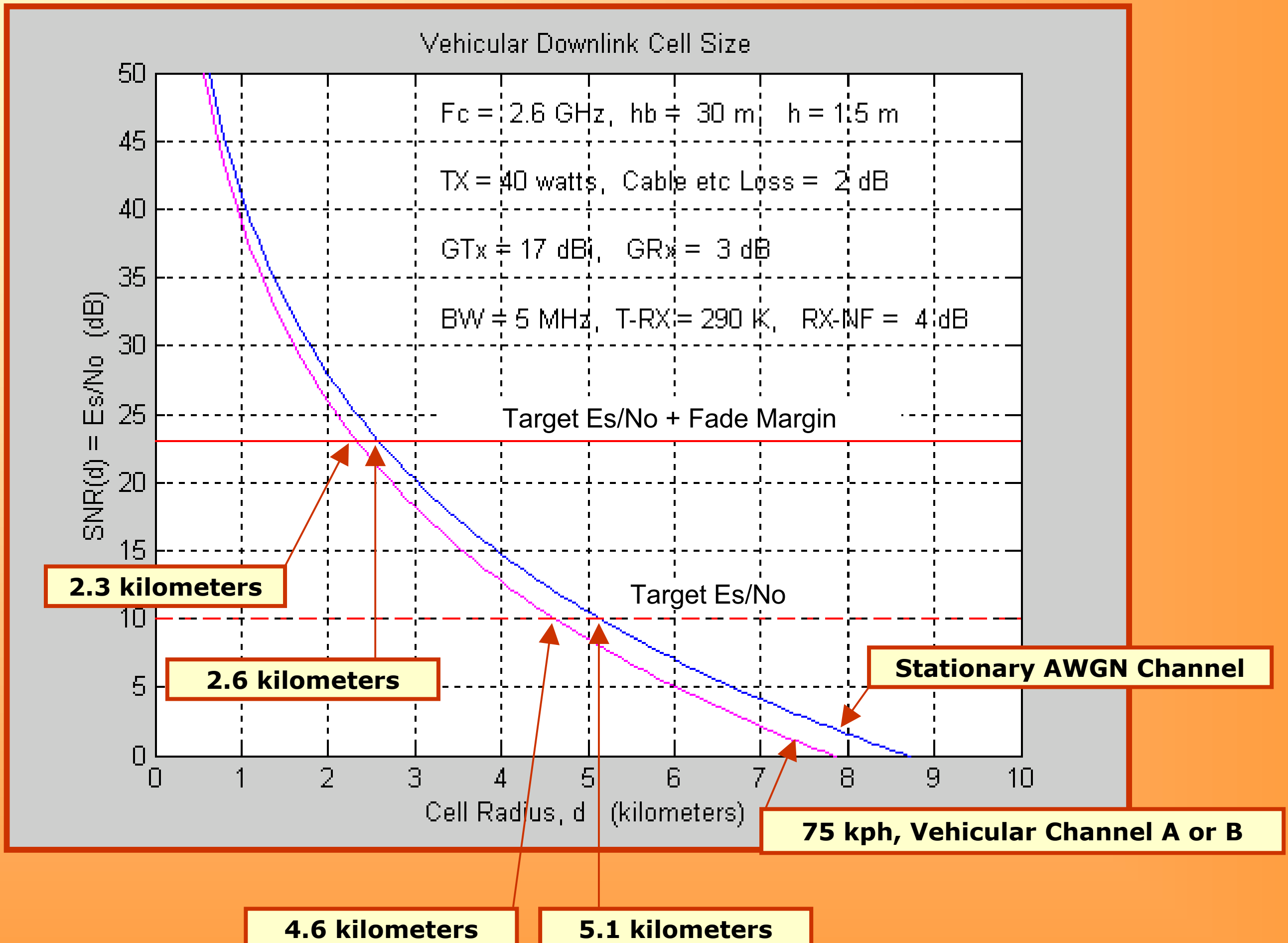
SBE multipath performance for Indoor Office Channel A/B is typically within 2 dB of perfect channel.

Uplink/Downlink Cell Radii

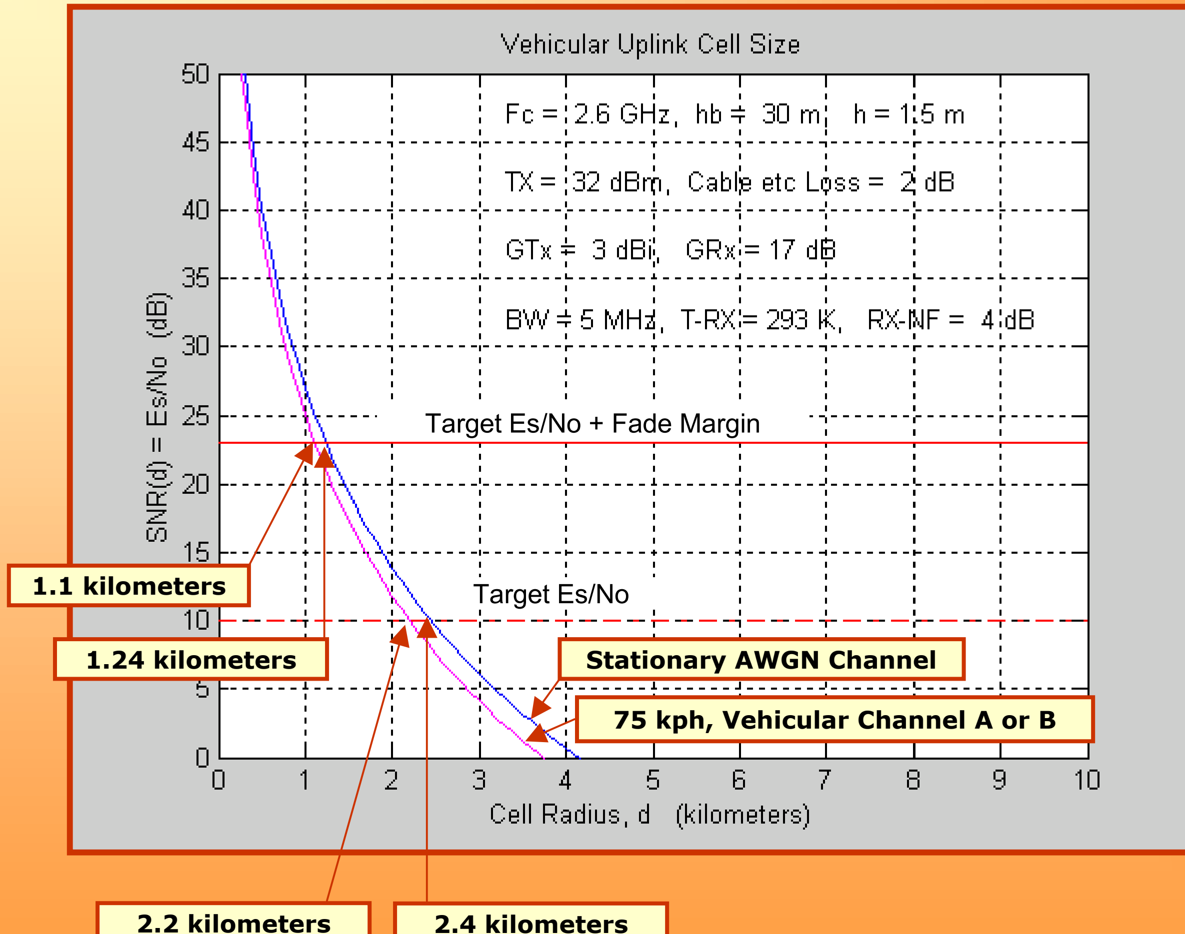
- Target Es/No (ahead of coding) = 10, 17, 23 dB (QPSK,16-QAM,64-QAM)
- Vehicular Test Environment
  - PE9 evaluation requirements, 5 MHz, 2.6 GHz
  - Cable/connector loss for BS = 2 dB
  - SC power back-off advantage for MS = 5, 2.6, 2 dB (QPSK,16-QAM,64-QAM) [1]
  - < 150 kph, channel A or B, Multipath/Doppler SNR degradation = 2 dB [2]
  - SNR Degraded, rate ½ QPSK Cell Radii
    - DL = 2.3 kilometers
    - UL = 1.1 kilometers
- Outdoor-to-Indoor & Pedestrian Test Environment
  - PE8 evaluation requirements, 5 MHz, 2.6 GHz
  - Cable/connector loss for BS = 2 dB
  - SC power back-off advantage for MS = 5, 2.6, 2 dB
  - 3 kph, channel A or B, Multipath/Doppler SNR degradation = 2 dB [2]
  - SNR Degraded, rate ½ QPSK Cell Radii
    - DL = 848 meters (outdoor) / 205 meters (indoor)
    - UL = 448 meters (outdoor) / 109 meters (indoor)
- Indoor Office Test Environment
  - PE7 evaluation requirements, 5 MHz
  - SC power back-off advantage for MS = 5, 2.6, 2 dB
  - 3 kph, channel A or B, Multipath/Doppler SNR degradation = 2 dB [2]
  - SNR Degraded, rate ½ QPSK Cell Radii
    - DL = 19 meters
    - UL = 13 meters

[1] Based on IEEE 802.16.3c-01/46. [2] Based on SBE simulations.

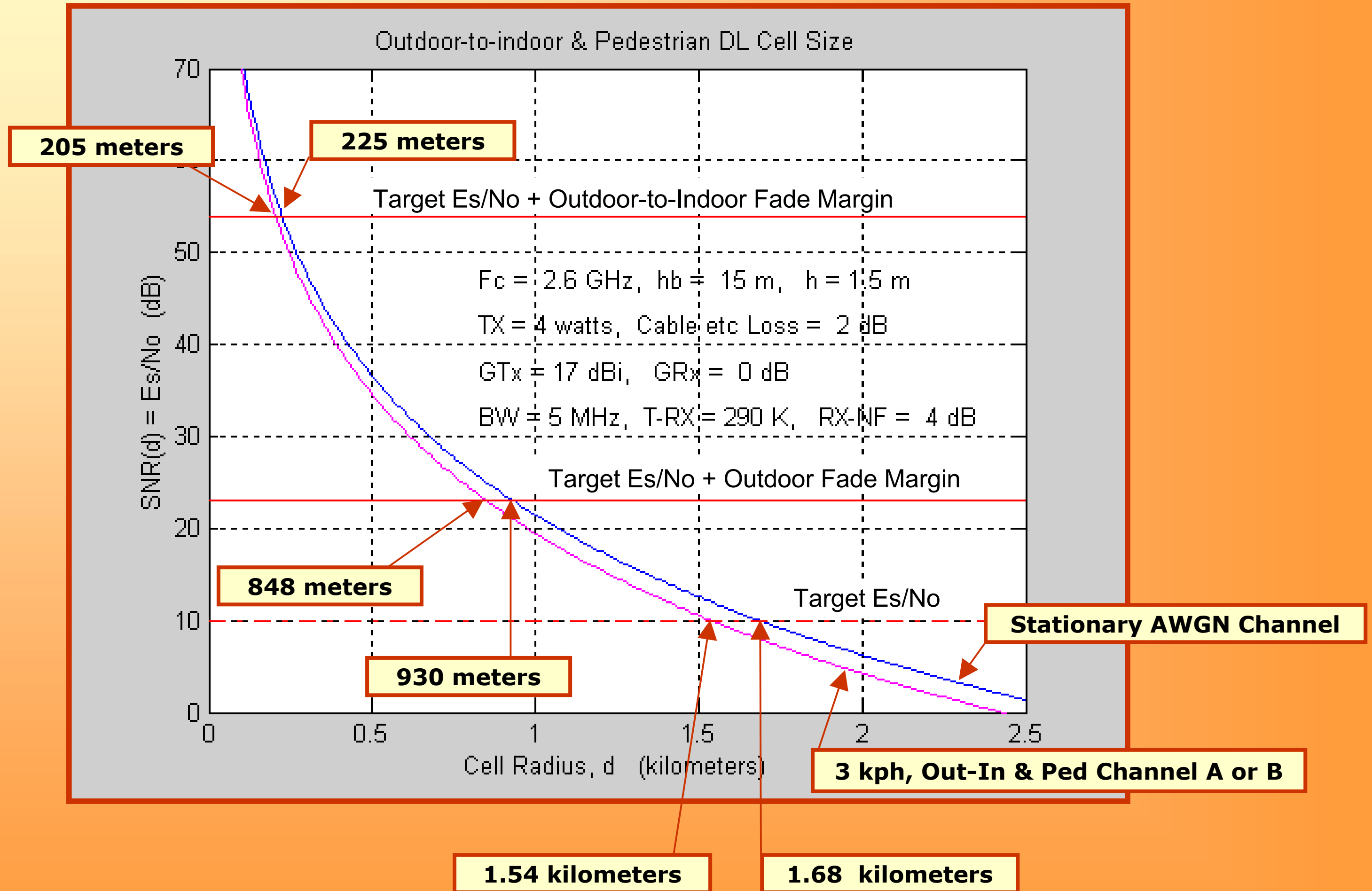
Vehicular DL Cell Size (PE9)
2.6 GHz, 5 MHz BW, rate ½ QPSK



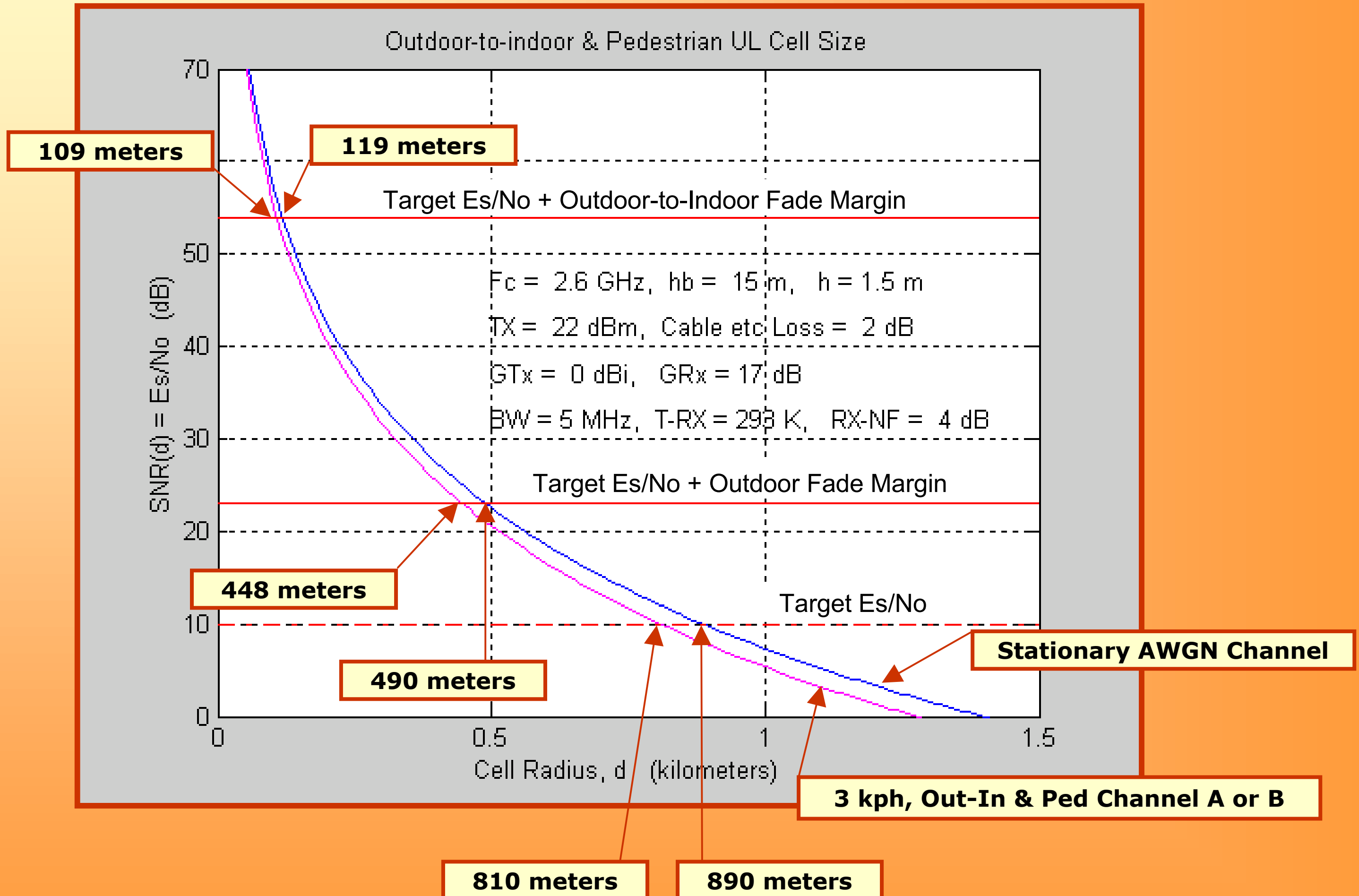
Vehicular UL Cell Size (PE9)
2.6 GHz, 5 MHz BW, rate ½ QPSK



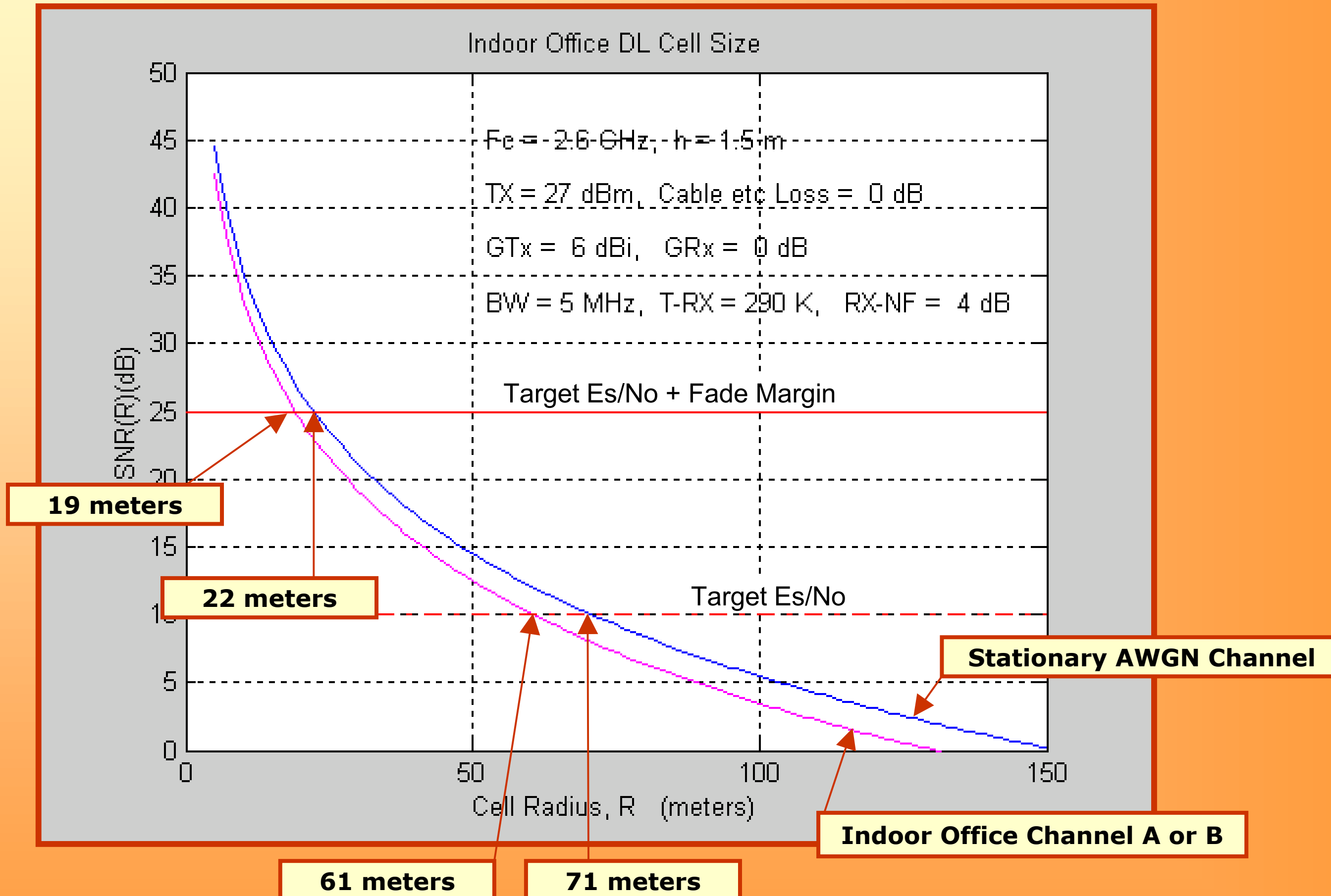
Outdoor-to-indoor & Pedestrian DL Cell Size (PE8)
2.6 GHz, 5 MHz BW, rate ½ QPSK



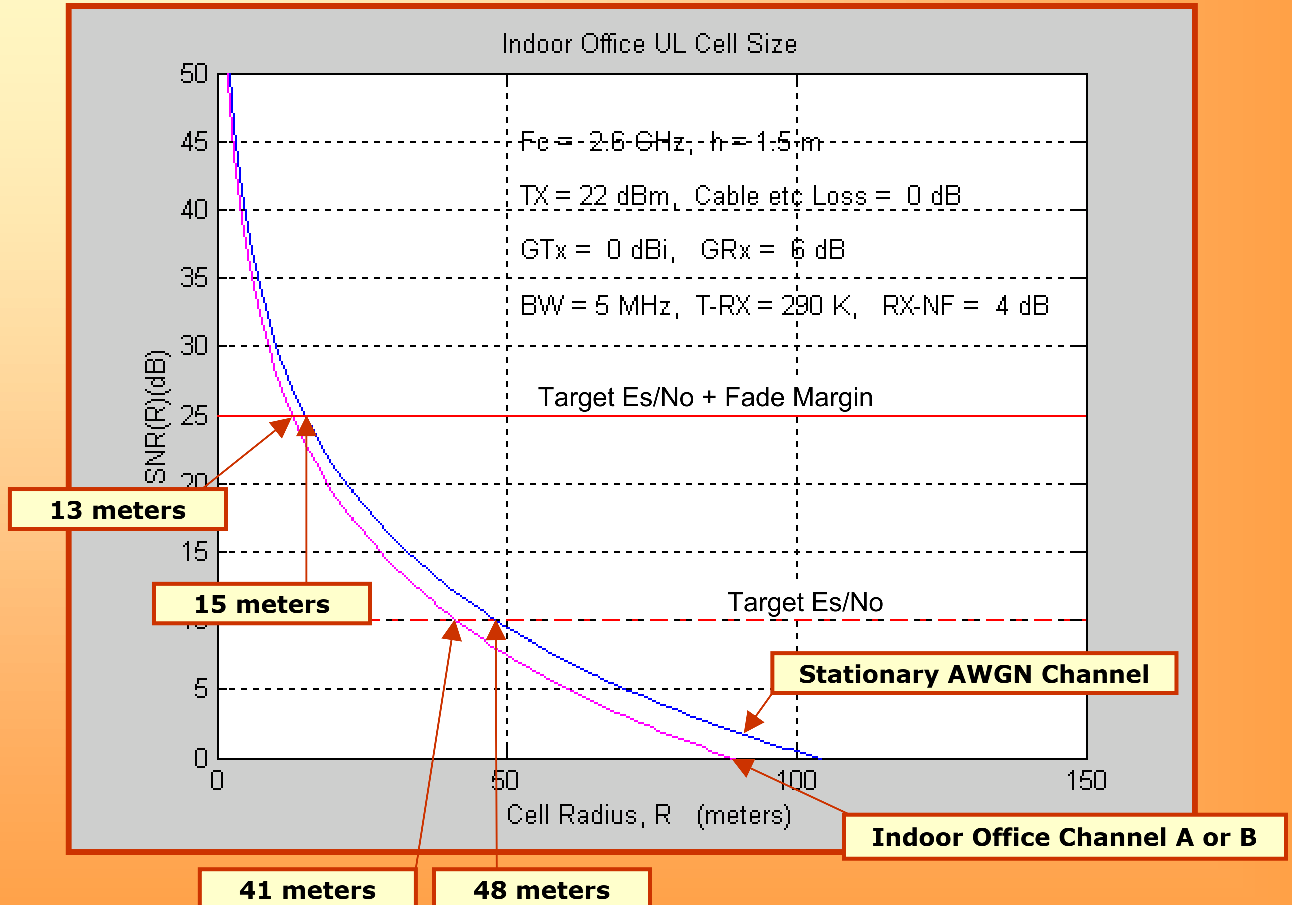
Outdoor-to-indoor & Pedestrian UL Cell Size (PE8)
2.6 GHz, 5 MHz BW, rate ½ QPSK



Indoor Office DL Cell Size (PE7)
2.6 GHz, 5 MHz BW, rate ½ QPSK



Indoor Office UL Cell Size (PE7)
2.6 GHz, 5 MHz BW, rate ½ QPSK



Conclusions on Mobile WirelessMAN-SCa

- Satisfactory NLOS Link Performance for Vehicular Doppler/Multipath
  - SBE capability in BS & MS
  - Pilot Word Insertion as necessary
    - Not required for short bursts (BW-REQ,RNG-RESP) or low speeds
    - Acceptable overhead for longer bursts
    - Up to 300 kph in 5 MHz BW (up to 20% PW overhead)
  - SNR Degradation ~2 dB from perfect channel (all test environments)
- UL Cell Radius ~ ½ DL Cell Radius?
  - Suggests UL PN Spreading Option for 802.16e WirelessMAN-SCa
  - Spreading Option Analysis & Proposal TBD
- BS-MS Ranging
  - BS measures ranging parameter for each RX burst
  - BS Issues RNG-RESP to keep MS within tolerance
- MAC Integration Issues
  - PHY requests Pilot Word Insertion (to MAC)?
  - Fixed/mobile robust modulation definition?
    - Additional Pilot Words (more robust within modulation type)
    - PN spreading option is UL only (no problem)

Uplink/Downlink Budgets for Cell Radius

- Vehicular Test Environment
  - PE9, etc. evaluation parameters
  - Stanford B path loss model
  - PE16 SNR performance degradation (SBE simulations)
- Outdoor-to-Indoor & Pedestrian Test Environment
  - PE8, etc. evaluation parameters
  - Stanford B path loss model
  - PE15 SNR performance degradation (SBE simulations)
- Indoor Office Test Environment
  - PE7, etc. evaluation parameters
  - ETSI Indoor Office path loss model
  - PE14 SNR performance degradation (SBE simulations)

Vehicular DL Cell Size (PE9)

Parameter	Value	Link Budget
Modulation	**QPSK 16-QAM 64-QAM**	**QPSK 16-QAM 64-QAM**
Bandwidth	5 MHz (PE1)	
TX Power	40 watts (PE9)	46 dBm
Cable, Connector Loss	2 dB	-2 dB
TX Ant. Gain (GTx)	17 dBi (PE9)	17 dB
TX Ant. Height (h_b)	30 meters (PE9)	
EIRP	TXPWR*GTx	61 dBm
RX Ant. Gain (GRx)	3 dB (PE9)	3 dB
RX Signal Power excluding PL(d)	EIRP*GRx	64 dBm
RX Noise Figure	4 dB (PE20)	
RX Noise Power	290 degrees Kelvin	-103 dBm
SNR (Es/No) excluding PL(d) (SNR_no_PL)	RX (Signal Power/Noise Power) dB	167 dB
Target Es/No (with Coding)	10 17 23 dB	10 17 23 dB
Fade Margin	13 dB (PE9)	13 dB
Required SNR	Target Es/No + Margin	23 30 36 dB
Allowed Path Loss PL(d)	Required SNR – SNR_no_PL dB	-144 -137 -131 dB
RX Ant. Height (ΔPL_h)	1.5 meters (PE9) = -.8 dB [1]	
RF Frequency (ΔPL_f)	2.6 GHz (PE3) = -.7 dB	
Cell Radius (d) for Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B (PE9)	2.6 1.8 1.3 km
75 kph Vehicular Channel A/B SNR Degradation (ΔSNR_{75})	2 dB [2]	
Allowed Path Loss PL(d) for 75 kph Vehicular Channel A/B	Required SNR + ΔSNR_{75} – SNR_no_PL dB	-142 -135 -129 dB
Cell Radius for (d) 75 kph Vehicular Channel A/B	Invert PL(d) for SUI Terrain Type B (PE9)	2.3 1.6 1.2 km

[1] Based on personal communications with Kirk Griffin, consultant. [2] Based on SBE simulations.

Vehicular UL Cell Size (PE9)

Parameter	**Value**	**Link Budget**
Modulation	**QPSK 16-QAM 64-QAM**	**QPSK 16-QAM 64-QAM**
Bandwidth	5 MHz (PE1)	
TX Power	27 dBm (PE9)	27 dBm
SC Power Back-off Advantage[1]	5 2.6 2 dB	5 2.6 2 dB
TX Ant. Gain (GTx)	3 dB (PE9)	3 dB
TX Ant. Height (h) (ΔPL_h)	1.5 meters (PE9), ΔPL_h = -.8 dB	
EIRP	TXPWR*GTx	35 32.6 32 dBm
RX Ant. Gain (GRx)	17 dBi (PE9)	17 dB
Cable, Connector Losses	2 dB	-2 dB
RX Signal Power excluding PL(d)	EIRP*GRx	50 47.6 47 dBm
RX Noise Figure	4 dB (PE20)	
RX Noise Power	290 degrees Kelvin	-103 dBm
SNR (Es/No) excluding PL(d) (SNR_no_PL)	RX (Signal Power/Noise Power) dB	153 150.6 150 dB
Target Es/No (with Coding)	10 17 23 dB	10 17 23 dB
Fade Margin	13 dB (PE9)	13 dB
Required SNR	Target Es/No + Margin	23 30 36 dB
Allowed Path Loss PL(d)	Required SNR – SNR_no_PL dB	-130 -120.6 -114 dB
RX Ant. Height (h_b)	30 meters (PE9)	
RF Frequency (ΔPL_f)	2.6 GHz (PE3) = -.7 dB	
Cell Radius (d) for Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B (PE9)	1.24 .76 .54 km
75 kph Vehicular Channel A SNR Degradation (ΔSNR_{75})	2 dB [2]	
Allowed Path Loss PL(d) for 75 kph Vehicular Channel A	Required SNR + ΔSNR_{75} – SNR_no_PL dB	-128 -118.6 -112 dB
Cell Radius (d) for 75 kph Vehicular Channel A	Invert PL(d) for SUI Terrain Type B (PE9)	1.1 .7 .48 km

[1] Based on IEEE 802.16.3c-01/46. [2] Based on SBE simulations.

Outdoor-to-indoor & Pedestrian DL Cell Size (PE8)

Parameter	Value	Link Budget
Modulation	**QPSK 16-QAM 64-QAM**	**QPSK 16-QAM 64-QAM**
Bandwidth	5 MHz (PE1)	
TX Power	4 watts (PE8)	36 dBm
Cable, Connector Loss	2 dB	-2 dB
TX Ant. Gain (GTx)	17 dBi (PE8)	17 dB
TX Ant. Height (h_b)	15 meters (PE8)	
EIRP	TXPWR*GTx	51 dBm
RX Ant. Gain (GRx)	0 dB (PE8)	0 dB
RX Signal Power excluding PL(d)	EIRP*GRx	51 dBm
RX Noise Figure	4 dB (PE20)	
RX Noise Power	290 degrees Kelvin	-103 dBm
SNR (Es/No) excluding PL(d) (SNR_no_PL)	RX (Signal Power/Noise Power) dB	154 dB
Target Es/No (with Coding)	10 17 23 dB	10 17 23 dB
Fade Margin to Indoor Pedestrian	13 + 20 + 11 = 44 dB (PE8)	44 dB
Fade Margin to Outdoor Pedestrian	13 dB (PE8)	13 dB
Required SNR (Indoor/Outdoor)	Target Es/No + Margin	54/23 61/30 67/36 dB
Allowed Path Loss PL(d) (Indoor/Outdoor)	Required SNR – SNR_no_PL dB	-100/131 -93/124 -87/118 dB
RX Ant. Height (ΔPL_h)	1.5 meters (PE8) = -.8 dB	
RF Frequency (ΔPL_f)	2.6 GHz (PE3) = -.7 dB	
Cell Radius for Indoor Ped w Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B (PE8)	225 165 125 m
Cell Radius for Outdoor Ped w Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B	930 675 513 m
3 kph Out-to-In & Ped Chan A/B SNR Degradation (ΔSNR_M)	2 dB [1]	
Cell Radius for Indoor 3 kph Ped Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	205 150 114 m
Cell Radius for Outdoor 3 kph Ped Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	848 615 468 m

[1] Based on SBE simulations.

Outdoor-to-indoor & Pedestrian UL Cell Size (PE8)

Parameter	Value	Link Budget
Modulation	**QPSK 16-QAM 64-QAM**	**QPSK 16-QAM 64-QAM**
Bandwidth	5 MHz (PE1)	
TX Power	17 dBm (PE8)	17 dBm
SC Power Back-off Advantage[1]	5 2.6 2 dB	5 2.6 2 dB
TX Ant. Gain (GTx)	0 dB (PE8)	0 dB
TX Ant. Height (h) (ΔPL_h)	1.5 meters (PE8), ΔPL_h = -.8 dB	
EIRP	TXPWR*GTx	22 19.6 19 dBm
RX Ant. Gain (GRx)	17 dBi (PE8)	17 dB
Cable, Connector Loss	2 dB	-2 dB
RX Signal Power excluding PL(d)	EIRP*GRx	37 34.6 34 dBm
RX Noise Figure	4 dB (PE20)	
RX Noise Power	290 degrees Kelvin	-103 dBm
SNR (Es/No) excluding PL(d) (SNR_no_PL)	RX (Signal Power/Noise Power) dB	140 137.6 137 dB
Target Es/No (with Coding)	10 17 23 dB	10 17 23 dB
Fade Margin to Indoor Pedestrian	13 + 20 + 11 = 44 dB (PE8)	44 dB
Fade Margin to Outdoor Pedestrian	13 dB (PE8)	13 dB
Required SNR (Indoor/Outdoor)	Target Es/No + Margin	54/23 61/30 67/36 dB
Allowed Path Loss PL(d) (Indoor/Outdoor)	Required SNR – SNR_no_PL dB	-86/117 -77/108 -70/101 dB
RX Ant. Height (ΔPL_h)	1.5 meters (PE8) = -.8 dB	
RF Frequency (ΔPL_f)	2.6 GHz (PE3) = -.7 dB	
Cell Radius for Indoor Ped w Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B (PE8)	119 79 57 m
Cell Radius for Outdoor Ped w Stationary AWGN Channel	Invert PL(d) for SUI Terrain Type B (PE8)	490 325 236 m
3 kph Out-to-In & Ped Chan A/B SNR Degradation (ΔSNR_M)	2 dB[2]	
Cell Radius for Indoor Ped w 3 kph Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	109 72 53 m
Cell Radius for Outdoor Ped w 3 kph Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	448 297 216 m

[1] Based on IEEE 802.16.3c-01/46.

[2] Based on SBE simulations.

Indoor Office DL Cell Size (PE7)

Parameter	**Value**	**Link Budget**
Modulation	**QPSK 16-QAM 64-QAM**	**QPSK 16-QAM 64-QAM**
Bandwidth	5 MHz (PE1)	
TX Power	27 dBm (PE7)	27 dBm
TX Ant. Gain (GTx)	6 dBi (PE7)	6 dB
EIRP	TXPWR*GTx	33 dBm
RX Ant. Gain (GRx)	0 dB (PE7)	0 dB
RX Signal Power excluding L(R)	EIRP*GRx	33 dBm
RX Noise Figure	4 dB (PE20)	
RX Noise Power	290 degrees Kelvin	-103 dBm
SNR (Es/No) excluding L(R) (SNR_no_PL)	RX (Signal Power/Noise Power) dB	136 dB
Target Es/No (with Coding)	10 17 23 dB	10 17 23 dB
Fade Margin	15 dB (PE7)	15 dB
Required SNR	Target Es/No + Margin	25 32 38 dB
Allowed Path Loss L(R)	Required SNR – SNR_no_PL dB	-111 -104 -98 dB
Cell Radius for Indoor Office w Stationary AWGN Channel	Invert L(R) for Indoor Office (PE7) [1]	22.3 13.1 8.3 m
3 kph Indoor Office Channel A/B SNR Degradation (ΔSNR_M)	2 dB [2]	
Cell Radius for 3 kph Indoor Office Channel A/B	Invert L(R) for Indoor Office (PE7)	19.2 11.2 7.1 m

[1] Path loss model in PE7 described in B.1.4.1.1 of UMTS; Selection Procedures etc, TR 101 112 V3.2.1 (1998-04).

[2] Based on SBE simulations.

Indoor Office UL Cell Size (PE7)

Parameter	Value			Link Budget		
Modulation	**QPSK**	**16-QAM**	**64-QAM**	**QPSK**	**16-QAM**	**64-QAM**
Bandwidth	5 MHz (PE1)					
TX Power	27 dBm (PE7)			17 dBm		
SC Power Back-off Advantage[1]	5	2.6	2 dB	5	2.6	2 dB
TX Ant. Gain (GTx)	0 dB (PE7)			0 dB		
EIRP	TXPWR*GTx			22	19.6	19 dBm
RX Ant. Gain (GRx)	6 dBi (PE7)			6 dB		
RX Signal Power excluding L(R)	EIRP*GRx			28	25.6	25 dBm
RX Noise Figure	4 dB (PE20)					
RX Noise Power	290 degrees Kelvin			-103 dBm		
SNR (Es/No) excluding L(R) (SNR_no_PL)	RX (Signal Power/Noise Power) dB			131	128.6	128 dB
Target Es/No (with Coding)	10	17	23 dB	10	17	23 dB
Fade Margin	15 dB (PE7)			15 dB		
Required SNR	Target Es/No + Margin			25	32	38 dB
Allowed Path Loss L(R)	Required SNR – SNR_no_PL dB			-106	-96.6	-90 dB
Cell Radius for Indoor Office w Stationary AWGN Channel	Invert L(R) for Indoor Office (PE7) [2]			15.2	7.4	4.5 m
3 kph Indoor Office Channel A/B SNR Degradation (ΔSNR_M)	2 dB [3]					
Cell Radius for 3 kph Indoor Office Channel A/B	Invert L(R) for Indoor Office (PE7)			13	6.4	3.8 m

[1] Based on IEEE 802.16.3c-01/46.

[2] Path loss model in PE7 and described in B.1.4.1.1 of UMTS; Selection Procedures etc, TR 101 112 V3.2.1 (1998-04).

[3] Based on SBE simulations.