Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**802.16e Proposal: Link Performance of WirelessMAN-SCa Mobile Subscriber Stations**
Date Submitted	**2003-03-11**
Source(s)	Russell McKown MacPhy Modems, Inc. 1104 Pittsburg Landing Richardson, TX 75080 Voice: 214.892.8903 Fax: 972.671.1445 russell@macphymodems.com
Re:	"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.
Abstract	Analysis of the performance available using the existing 802.16a single carrier physical layer for mobile subscriber stations. Description of the link performance based on a single burst equalization technique and the specified evaluation requirements.
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.
Notice	
Release	
Patent Policy and Procedures	

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

Russell McKown, Ph.D.
MacPhy Modems, Inc.

1 Introduction

The IEEE Standard Amendment 802.16a is inclusive in that multiple physical layers are specified for fixed broadband wireless access systems operating in both licensed and licensed exempt bands of the 2 to 11 GHz radio spectrum. The IEEE conveniently refers to these 802.16 systems as WirelessMAN^{TM} (wireless metropolitan area network) systems. The 802.16a amendment specifies three physical layer signaling techniques: single carrier (WirelessMAN-SCa), orthogonal frequency division multiplexing (WirelessMAN-OFDM) and orthogonal frequency division multiple access (WirelessMAN-OFDMA).

This proposal describes how the existing WirelessMAN-SCa specification is adequate -- in terms of multipath and Doppler mitigation -- for the deployment of mobile subscriber stations (MS). This is a direct consequence of the ability to give the WirelessMAN-SCa MS receiver the same single burst equalization (SBE) technology that currently benefits WirelessMAN-SCa base stations (BS). SBE allows the WirelessMAN-SCa BS to provide high performance multiple subscriber (fixed or not), multipath reception (including NLOS). The MS can use the SBE to be robust with respect to multipath and Doppler.

The link budget analysis, however, indicates a range asymmetry between the downlink (DL) and uplink (UL). The DL range is approximately twice the UL range for the same modulation/encoding level, say rate ½ QPSK. This suggests enhancements to the WirelessMAN-SCa physical layer are necessary to increase the range of the UL.

2 SBE Overview

By our definition, a single burst equalization or SBE technology achieves near optimal reception for an arbitrary RF burst with essentially no prior knowledge of the propagation channel and only reasonable prior knowledge of the RF burst carrier frequency, symbol timing and/or amplitude.

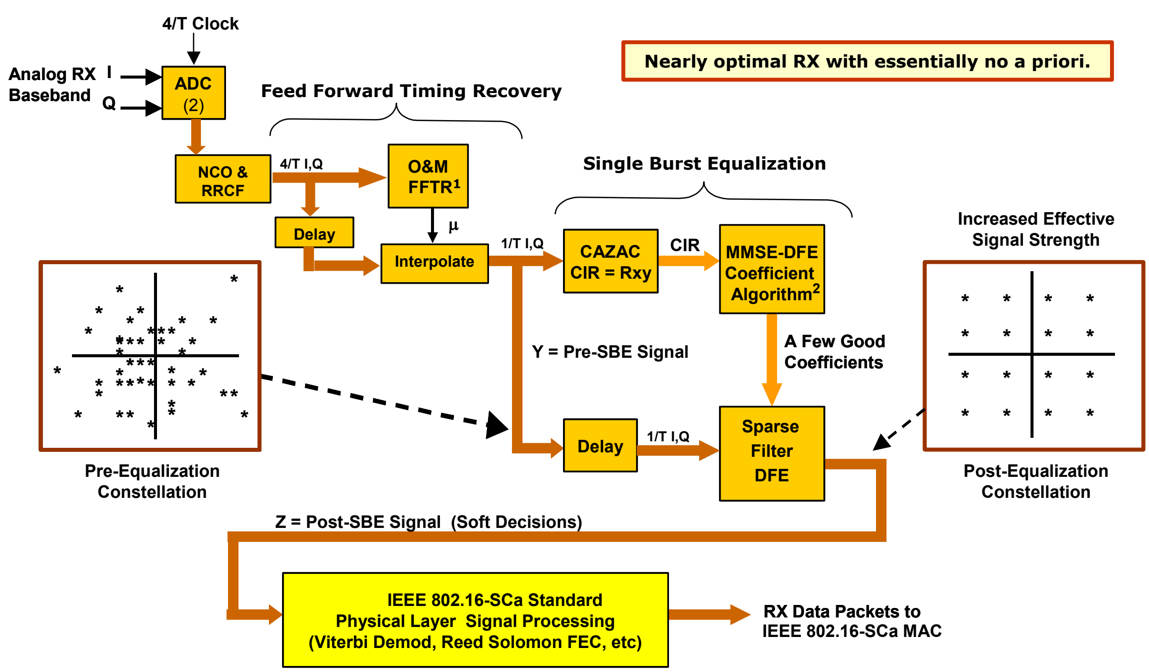
Although a specific SBE technology is presented herein, "SBE" for these purposes can be considered a generic solution to the BS multiple subscriber, multipath reception problem. Thus, any alternative receiver technologies or methods that solve the multipoint-to-point, short burst, multipath receiver problem qualify as an SBE technology. It is known that the particular SBE technology presented herein is capable of being economically included in the modem of a WirelessMAN-SCa MS station. Others SBE technologies may share that capability.

Figure 2-1 shows the SBE baseband signal processing as a pre-processor to a WirelessMAN-SCa baseband receiver. After feed forward timing recovery, the Pilot Word preamble is processed to obtain a channel impulse response (CIR) estimate. The CIR is input to an "MMSE-DFE" coefficient computation algorithm as described in reference 1. Figure 2-2 shows in slightly more detail that the MMSE-DFE coefficient computation and a subsequent tap selection procedure provide two sparse filter coefficient vectors, one for the feed-forward equalization (FFE) filter and one for the feedback equalization (FBE) filter. The FFE and FBE filters are the key components of a decision feedback equalizer (DFE). The sparse FFE and FBE filters can be efficiently implemented in the time domain since there are only a few non-zero coefficients, e.g., fewer than 12 each, say, out of the available 64 or 256 taps in the FFE or FBE filters.

Figure 2-3 illustrates the SBE input, Y, distorted by a SUI-5 channel, the sparse FFE filter output, Y-FFE, the sparse FBE filter output, Y-FBE, and the SBE output, Z = Y-FFE + Y-FBE. Amazingly the equalized signal Z recovers the original TX data – which is plotted in red in the lowest subplot. The accuracy of the SBE output is evident, -- the SBE output Z is in very good agreement with the TX data. The SBE recovers the transmitted data of interest.

The received signal is simply delayed until the FFE and FBE coefficients are available. The application of the SBE to the WirelessMAN-SCa BS defines SBE cycle time requirements as illustrated in Figure 2-4. The BS SBE must be able to process a continuous stream of the shortest uplink bursts (BW-REQ) from different subscribers. The result, for the applications considered here (i.e., 10 MHz or less bandwidth) is an SBE cycle time requirement of 47 microseconds or less.

This real time SBE technology that solves the multiple subscriber, multipath problem of the fixed WirelessMAN-SCa BS can also be implemented in a WirelessMAN-SCa MS. This allows both the BS & MS to use the SBE to solve the multipath problem with vehicular rate Doppler.



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).

Figure 2-1. Single burst equalization pre-processor for WirelessMAN-SCa

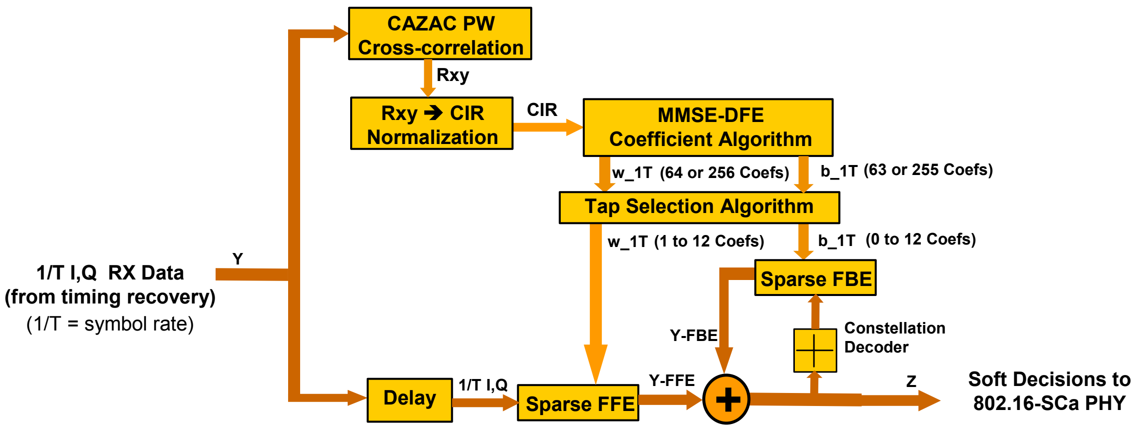


Figure 2-2. SBE consisting of CIR estimate, MMSE-DFE / Tap Selection and sparse DFE.

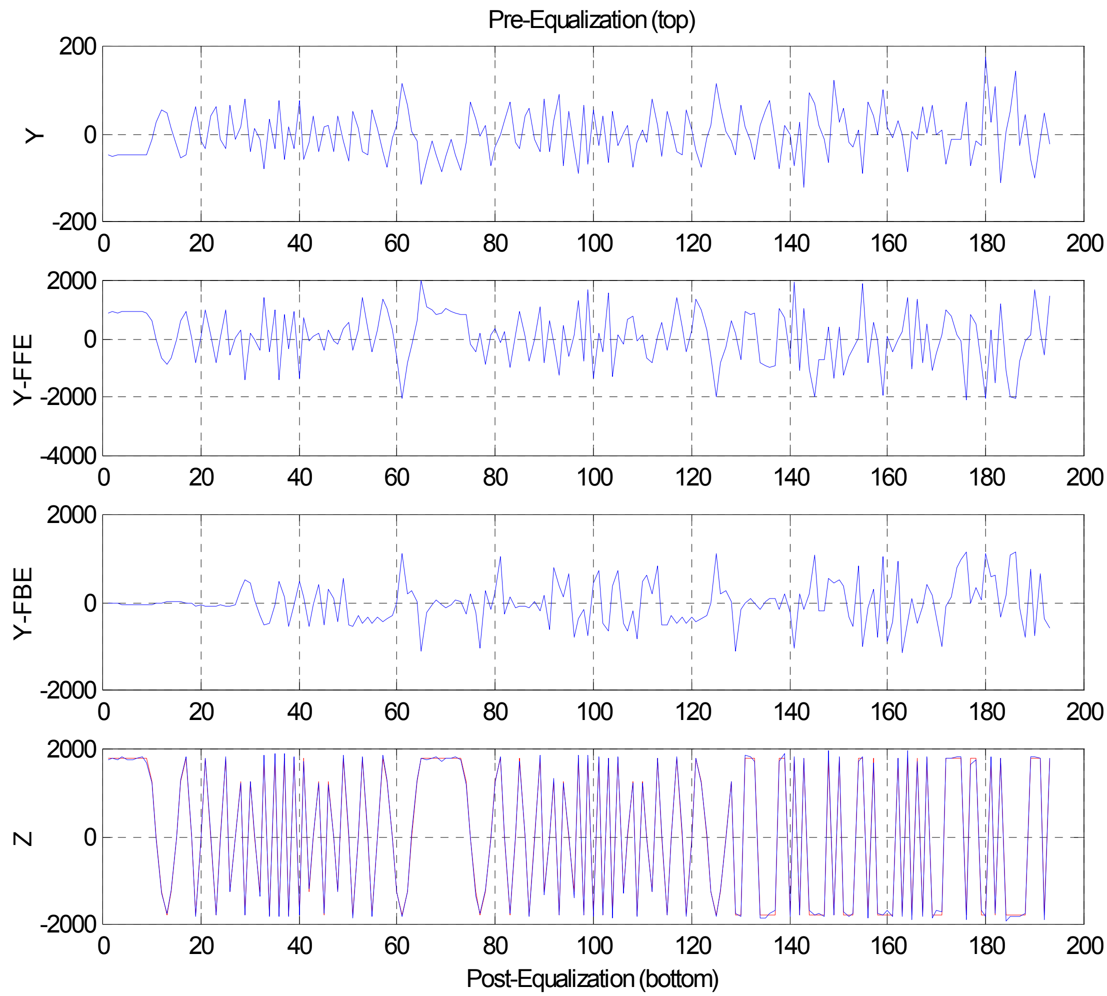


Figure 2-3. Y = SBE input, Y-FFE = FFE output, Y-FBE = FBE output, Z = Y-FFE + Y-FBE = SBE output. (The TX data of interest is plotted in red in the lower subplot. Channel is SUI-5 of reference 4.)

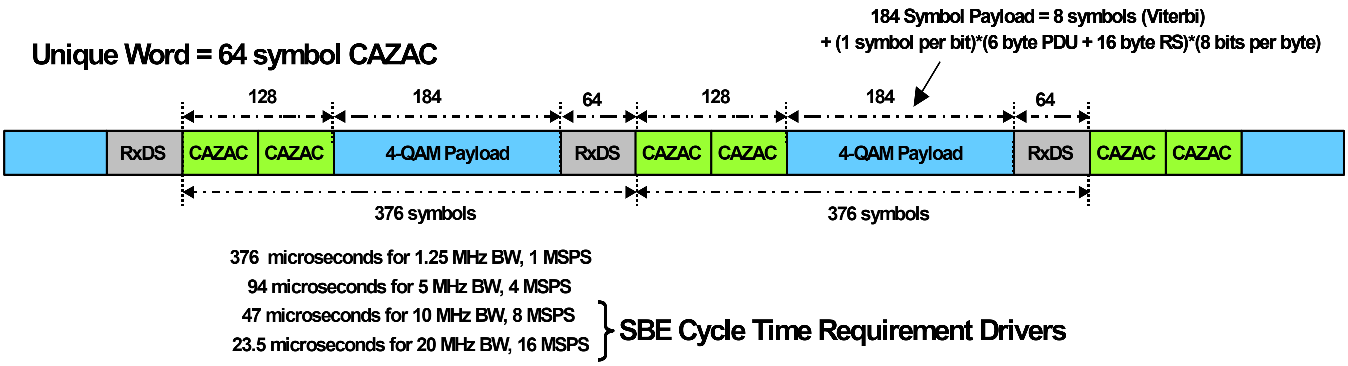


Figure 2-4 SBE cycle time requirement based on a BW-REQ message stream to a WirelessMAN-SCa BS.

Finally, the SBE pre-processor technology can conceivably be adapted to the WirelessMAN-OFDM and WirelessMAN-OFDMA systems that currently use an estimate of the channel transfer function amplitude and phase to coherently compensate for the spectral effects of multipath propagation. WirelessMAN-SCa systems with SBE will exhibit superior link performance when compared to other WirelessMAN systems without SBE in difficult multipath NLOS environments. For WirelessMAN-OFDM and WirelessMAN-OFDMA, this results from the DFE based SBE pre-processing preventing the loss of channel capacity that is otherwise associated with severe multipath spectral fades. Figure 2-5 illustrates this point with the power spectra of pre-SBE and post-SBE signals for the ETSI Vehicular Test Environment Channel A (reference 2).

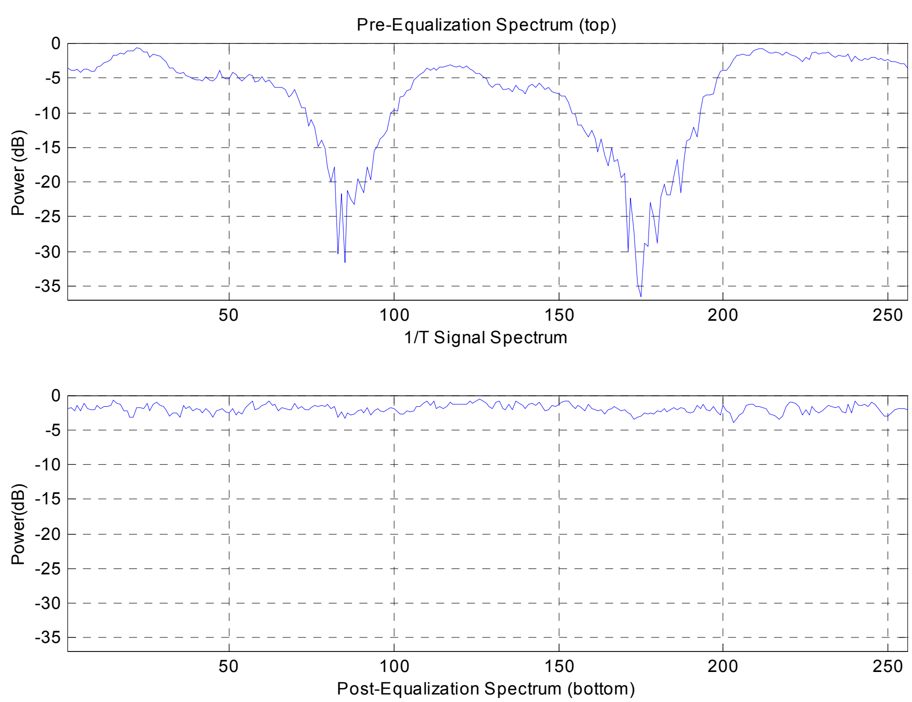


Figure 2-5. Power spectra of pre-SBE and post-SBE signals for ETSI Vehicular Test Channel A.

3 Mobility Design Concept for WirelessMAN-SCa PHY

As mentioned, the fundamental design concept is that the WirelessMAN-SCa MS can use the same SBE pre-processor technology employed by the WirelessMAN-SCa BS. The SBE processes the Pilot Word preamble to get a CIR estimate that in turn is used to compute the sparse FFE and FBE filter coefficients for a computationally efficient MMSE-DFE. This makes the BS-MS link robust with respect to both severe multipath and high Doppler rates.

For any channel changes, due to Doppler or otherwise, that are slow compared to the duration of the received burst, the channel is nearly stationary during the burst. This provides that FFE and FBE filter coefficients in the MMSE-DFE can remain static for the duration of the burst. Decision aided carrier phase recovery and gain control are still a good idea however.

For faster channel changes, such as Doppler from high speed vehicular MS, the MAC can insert additional Pilot Words at intervals defined by the Pilot Word Interval parameter in the DCD and UCD messages. These additional Pilot Words can be used by the SBE to recompute the FFE and FBE filter coefficients. This allows the MMSE-DFE to keep up with changes in the channel that occur within a burst.

The Pilot Word Intervals that are available from the existing 802.16/802.16a standard are $2^{<value+2>}$ symbols, where value is 2 to 10, e.g. the available Pilot Word Interval set is the binary power sequence 16, 32, 64 … to 4096. Performance evaluation simulations serve as a basis for determining the Pilot Word Intervals of interest to WirelessMAN-SCa for IEEE Project 802.16e.

Figure 3-1 illustrates a burst with an additional Pilot Word inserted at an interval of 512 symbols. It is convenient to define a Demod Interval as the maximum symbol distance from a Pilot Word. The performance of the SBE enabled MS-BS link depends on the product of the Doppler (Hz) times the Demod Interval (seconds) or, if one prefers, the product of velocity times the Demod Interval.

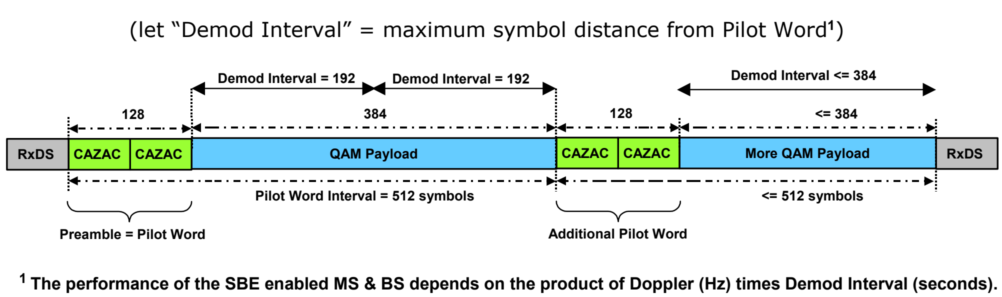


Figure 3-1. Use of an additional dual 64 CAZAC Pilot Word at an interval of 512 symbols.

Table 3-1 identifies the Pilot Word Intervals that are recommended at different bandwidths and vehicular speeds based on the performance simulations. In practice the decision to insert the additional Pilot Words is based on the SNR and error statistics of a BS-MS link. If the BS detects excessive errors while receiving an MS with an otherwise acceptable SNR, the BS can demand that additional Pilot Words be inserted into the uplink burst from that MS. The BS would express this demand in a change to the Pilot Word Interval parameter in the DCD. Alternatively, the MS may request the BS to change to the Pilot Word Interval parameter by issuing the appropriate RNG-REQ message to the BS. The BS may implement the request as a change in the Pilot Word Interval parameter of the UCD.

Table 3-1 Recommended Pilot Word Interval in symbols for a MS-BS link as function of BW and velocity[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%)

[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.

Also shown in Table 3-1 is the amount of overhead created by the insertion of the additional Pilot Words. The additional Pilot Word for the 5, 10 & 20 MHz bandwidths is composed of two Unique Words each of which is a 64 symbol Frank CAZAC sequence. For the 1.25 MHz bandwidth the additional Pilot Word is two Unique Words each of which is a 16 symbol Frank CAZAC sequence.

For example, a MS traveling at 75 kph in a 5 MHz WirelessMAN-SCa system should be operating with a Pilot Word Interval of 2048 symbols. This introduces an additional overhead of 6% for that MS-BS link. In keeping with the Project 802.16e rule of not degrading the services provided to fixed SS, the TDD bandwidth allocation for this MS should be reduced by 6% from what it would be if no additional Pilot Words were necessary. This is a service provisioning issue.

4 Proposal Evaluation Results

This section presents results for the evaluation criteria of the reference document "Mobile System and Proposal Evaluation Requirements". The results presented were obtained with link level simulations. No results are available for proposal evaluation criteria PE10, PE11, PE12, PE17, PE18 and PE19 since these criteria require system level simulations of specific deployment scenarios that are beyond our current capabilities. However, the link level performance evaluations clearly establish the feasibility and desirability of the proposed methods.

The SBE functions as a pre-processor to the WirelessMAN-SCa specified processing, i.e., the SBE output is the input to the Viterbi demodulator. It is reasonable and convenient, therefore, to characterize an MS-BS link by the SNR of the SBE output relative to a target SNR. The target SNR is an equivalent Es/No value that provides reliable performance at a given modulation/encoding rate. Table 4-1 shows the Target SNR values used in this performance evaluation.

Table 4-1 Target SNR for Link Budgets (SER ~ 10^{-6} with coding)

Modulation / Encoding	Target Es/No (ahead of decoding)
QPSK / rate ½	10 dB
16-QAM / rate ¾	17 dB
64-QAM / rate ¾ (?)	23 dB

Link level simulations were performed in MATLAB for the specified channels described in reference 2. A complex passband signal was generated using a realistic TX filter chain and the signal convolved with the complex channel impulse response, CIR, under investigation. The appropriate level of white noise was added before converting to baseband using realistic RX filters and timing recovery / interpolation. The baseband SBE processing estimates the CIR from the Pilot Word and computes sparse coefficient vectors for the DFE. The SBE output is the sequence of pre-constellation decoder "soft decision" variates in the DFE (labeled Z in Figure 2-2).

The Doppler channel generation procedure was taken from Appendix B of reference 4 and included ~100 sets of independent channel realizations (new seed), each of which provides a sequence of appropriately sampled, Doppler perturbed CIR coefficients. The link simulation was evaluated at 4 values of Es/No for each CIR test and for multiple time adjacent CIR tests per channel realization test.

The performance measure of interest is the SNR of Z, the soft decision variate that is both the output of the SBE and the input to the Viterbi demodulator (or equivalent) implicitly required by the WirelessMAN-SCa PHY. The SNR of Z can be used to evaluate residual performance degradations for multipath channels compared to the Es/No for a perfect channel. The SNR of Z can also be used to evaluate the degradation due to Doppler perturbations of the CIR for a moving MS relative to a stationary MS with otherwise the same multipath channel. These degradations are a measure of how well the SBE recovers the signal of interest given the effects of multipath and Doppler.

Figure 4-1 illustrates the simulation concept and procedure used to estimate the SNR degradation due to the Doppler perturbation of the channel coefficients. The Doppler SNR degradation is estimated as the amount the SNR(Z) degrades from the start of the burst (SOB) to the end of the burst (EOB).

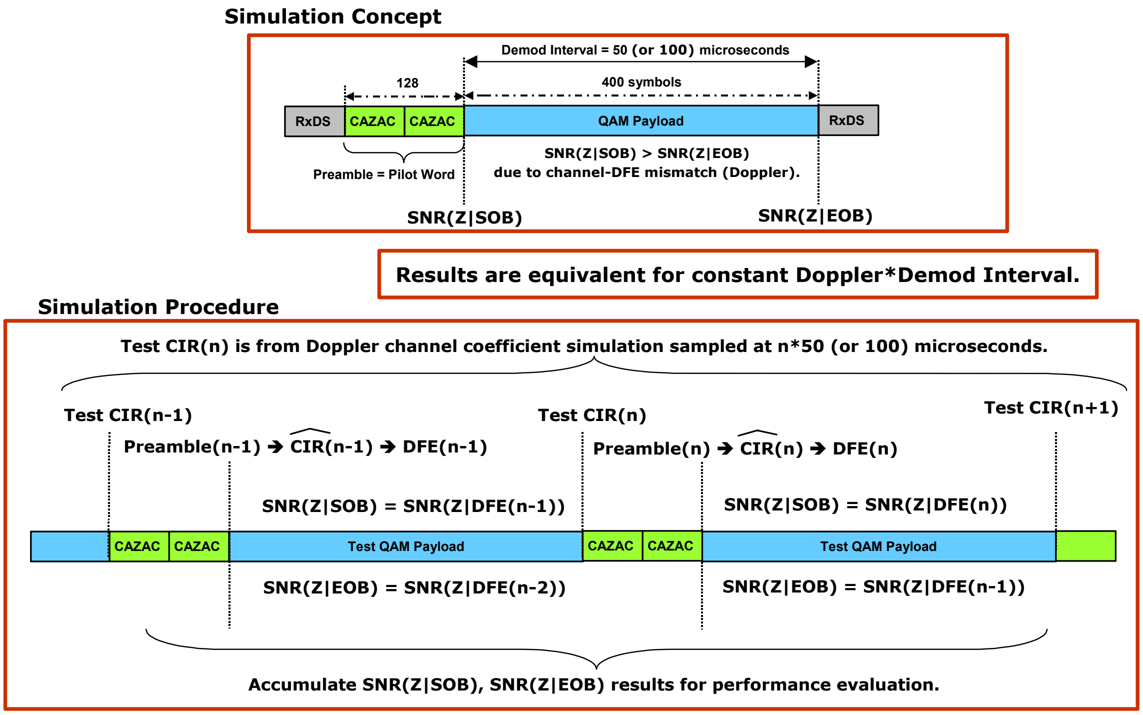


Figure 4-1. SBE simulation: Doppler SNR degradation = SNR(Z|EOB) - SNR(Z|SOB).

Figures 4-2 and 4-3 show sample results for individual 4 Es/No trial SBE link simulations. The plot on the right in both figures is a plot of the SNR of the SBE input, Y, and the SBE output, Z, versus the simulation Es/No. In essence this is a plot of the RX SNR versus the TX SNR. Figure 4-1 shows an example 4 Es/No trial that indicates the SBE preserves the ML performance of a perfect channel, e.g., the measured SER agrees with the theoretical QPSK error probability. The post-SBE RX SNR agrees with the TX SNR = Es/No (unity slope line). Figure 4-2 also shows a 1 to 2 dB implementation loss at high SNR that is evident in both the SBE input, Y, and the SBE output, Z. This is mostly due to the finite filters in the RX and TX chain.

Figure 4-3 shows an extreme example for an MS with a 1500 kph velocity in a familiar 5 MHz, SUI-3 channel (reference 4). The plot on the right shows the performance of the SBE output, Z, at SOB (red) and at the EOB (blue). The SNR(Z|EOB) shows Doppler degradation at this trial's 200 symbol or 50 microsecond Demod Interval. The Doppler degradation results from a mismatch between SBE DFE coefficients and the RX signal at the trial Demod Interval of 50 microseconds. The 1500 kph velocity corresponds to 3614 Hz Doppler and is considered the upper limit for a WirelessMAN-SCa MS-BS link.

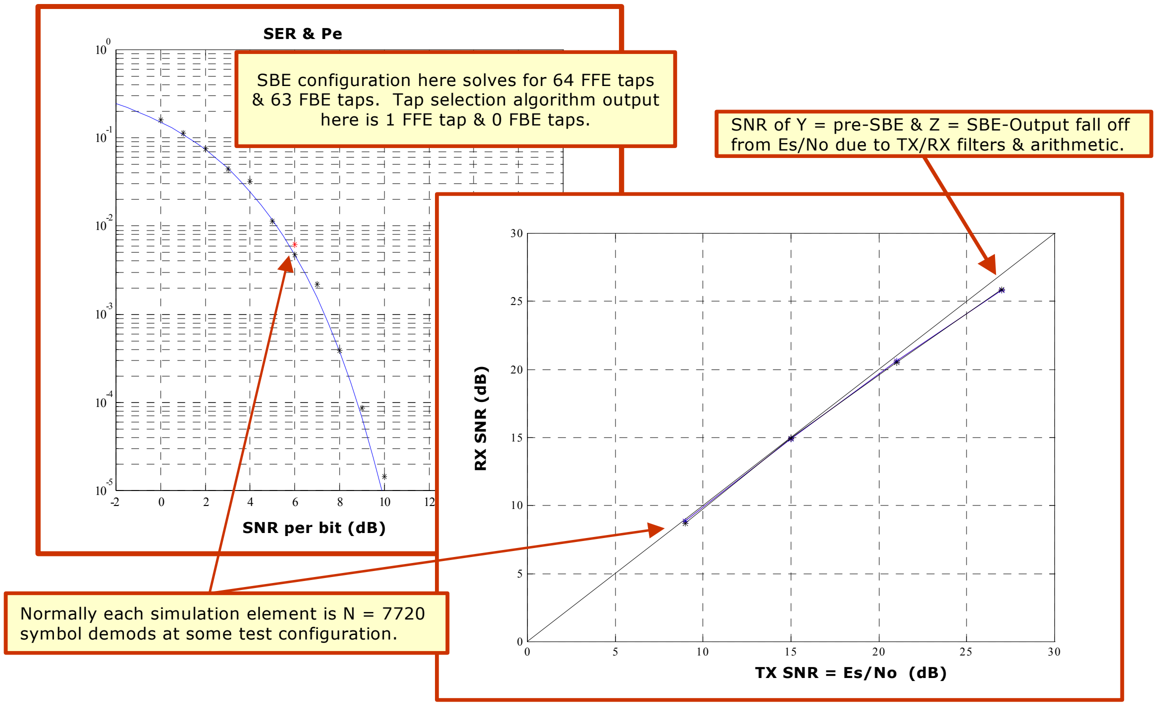


Figure 4-2. Perfect channel-AWGN-QPSK control.

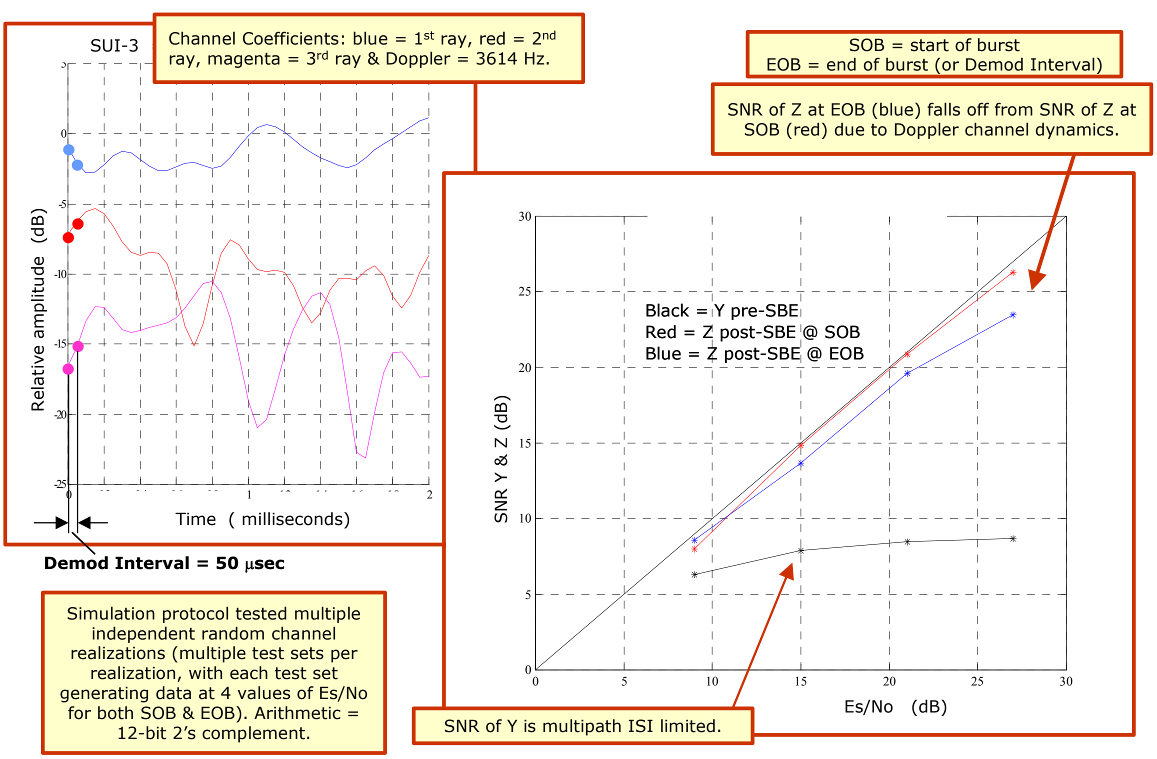


Figure 4-3. MS velocity = 1500 kph, SUI-3 channel, Demod Interval = 50 µsec.

4.1 Vehicular Test Environment (PE9 & PE16)

Tables 4.1-1 to 4.1-3 summarize the vehicular link performance for WirelessMAN-SCa MS using the SBE to mitigate the effects of Doppler and multipath. These simulation results are for a vehicular MS in a 5 MHz bandwidth channel at 2.6 GHz with the Channel A and B impulse responses described for the Vehicular Test Environment in reference 2.

Table 4.1-1 indicates the SNR degradation for a stationary MS is typically within 2 dB of the Es/No for a perfect AWGN channel. Tables 4.1-2 and 4.1-3 indicate that the SNR performance of a mobile MS is typically within 1 dB of a stationary MS for both Vehicular Test Channels A and B. The Demod Interval for these results is 400 symbols = 100 microseconds.[1]

As anticipated, there is no SNR degradation for a 3 kph pedestrian MS compared to a stationary MS. The 3 kph velocity corresponds to only a 7.3 Hz Doppler frequency – the CIR coefficients are essentially stationary over any reasonable TDD burst duration, say < 2 milliseconds or 8000 symbols for a 5 MHz bandwidth WirelessMAN-SCa system.

Table 4.1-1 SNR degradation of stationary Vehicular Channel A & B relative to perfect channel.

Es/No (dB)	Vehicular Channel A (stationary)	Vehicular Channel B (stationary)
9	-.6 +/- 1.1 dB	-.9 +/- .8 dB
15	-.3 +/- .8 dB [1]	-.9 +/- .8
21	-1.0 +/- 1.2	-2.2 +/- 1.4
27	-3.5 +/- 1.8	-5.0 +/- 2.1 dB [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 multipath performance for Vehicular Channel A or B is typically within ~2 dB of perfect channel performance.

Table 4.1-2 Mobility SNR degradation relative to stationary MS for Vehicular Channel A[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] These Mobility SNR Degradations were originally evaluated for 3, 75 and 150 kph per the proposal evaluation requirements of reference 3. The Demod Interval for the original evaluations was 100, 50 and 50 microseconds. However a scaling error was found with the result the evaluation was actually for 30, 750 and 1500 kph. The results in Tables 4.1-2 and 4.1-3 are based on equivalent performance for constant Doppler*Demod Interval product.

Table 4.1-3 Mobility SNR degradation relative to stationary MS for Vehicular Channel B[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.

Tables 4.1-4 and 4.1-5 give the QPSK/16-QAM/64-QAM link budgets for the Vehicular downlink and uplink, respectively. Figures 4.1-1 and 4.1-2 plot the RX SNR as a function of cell/sector radius for rate ½ QPSK. Based on the simulation results, a high speed vehicular WirelessMAN MS will experience ~2 dB SNR degradation relative to a perfect channel. The link budgets also include 2 dB cable/connector loss for the BS and an SC back-off advantage term for the MS UL TX based on reference 5.

The degraded Vehicular DL QPSK cell size is 2.3 kilometers which is slightly more than twice the degraded Vehicular UL QPSK cell size of 1.1 kilometers. This DL/UL asymmetry is clearly a limitation of the existing WirelessMAN-SCa physical layer that needs to be addressed in the 802.16e project.

Table 4.1-4 Link budget for Vehicular DL

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 kmph Vehicular Channel A/B SNR Degradation (ΔSNR_{75})	2 dB [2]	
Allowed Path Loss PL(d) for 75 kmph Vehicular Channel A/B	Required SNR + ΔSNR_{75} – SNR_no_PL dB	-142 -135 -129 dB
Cell Radius for (d) 75 kmph 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.

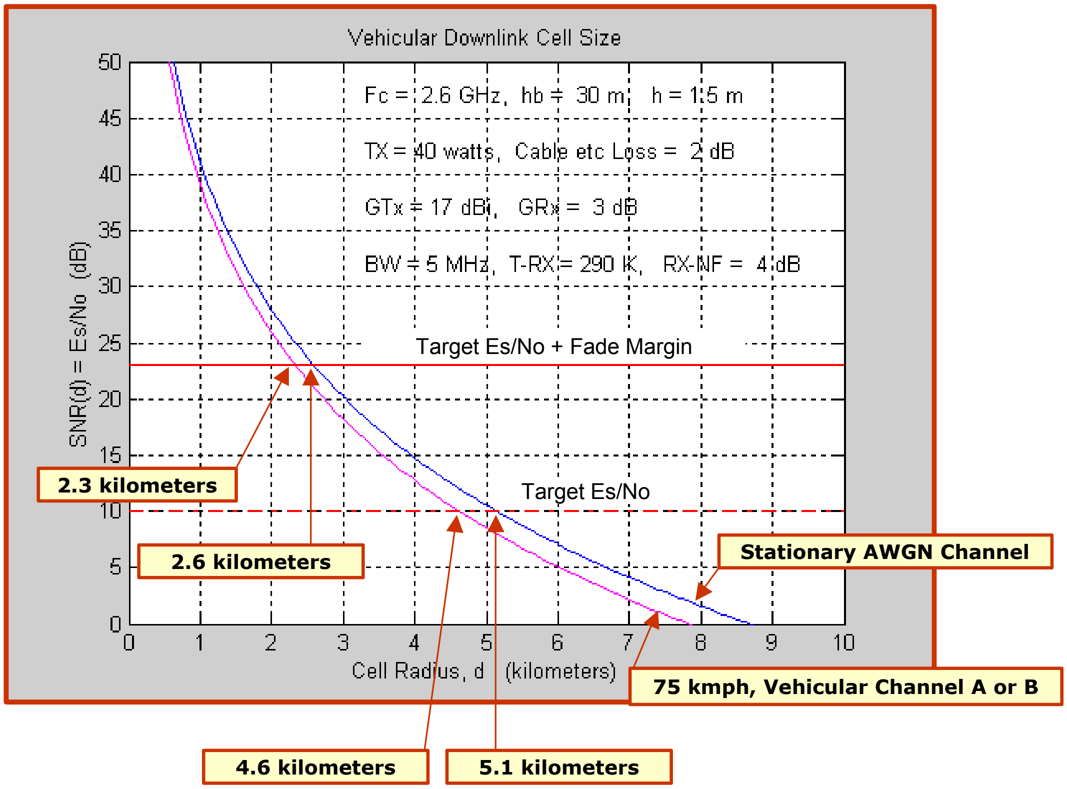


Figure 4.1-1 Vehicular DL cell size (2.6 GHz, 5 MHz BW, rate ½ QPSK) .

Table 4.1-5 Link budget for Vehicular UL

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 kmph Vehicular Channel A SNR Degradation (ΔSNR_{75})	2 dB [2]	
Allowed Path Loss PL(d) for 75 kmph Vehicular Channel A	Required SNR + ΔSNR_{75} – SNR_no_PL dB	-128 -118.6 -112 dB
Cell Radius (d) for 75 kmph 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.

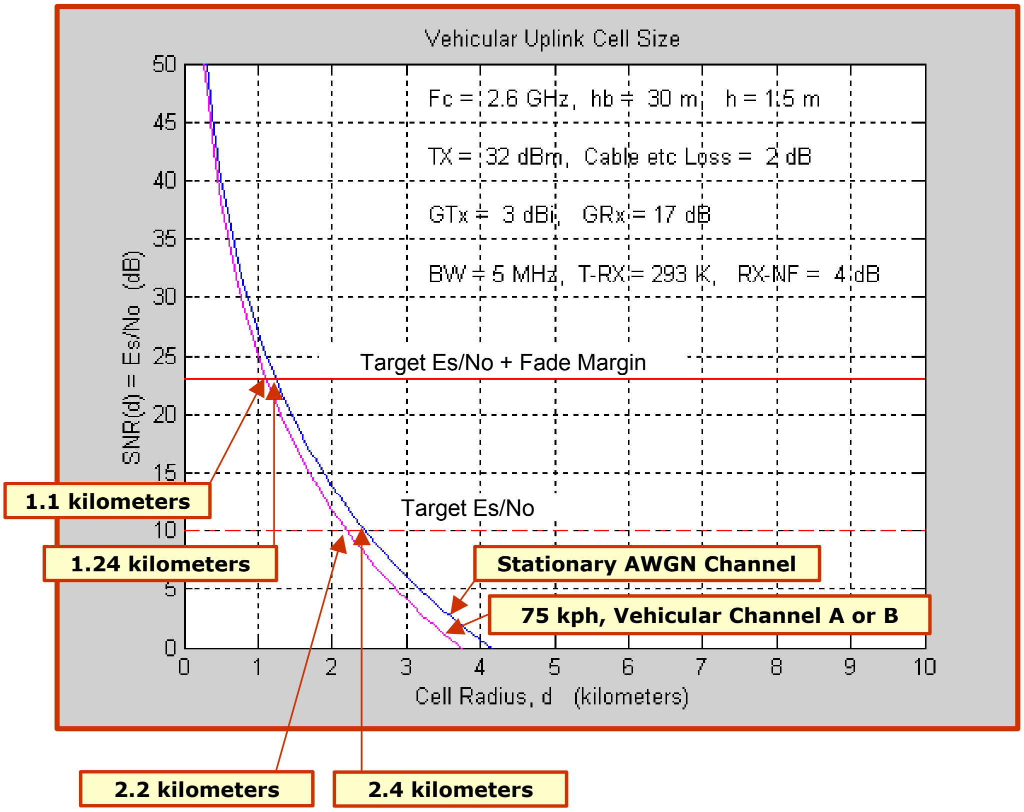


Figure 4.1-2 Vehicular UL cell size (2.6 GHz, 5 MHz BW, rate ½ QPSK) .

4.2 Outdoor-to-Indoor & Pedestrian Test Environment (PE8 & PE15)

Table 4.2-1 summarizes the "outdoor-to-indoor & pedestrian" link performance for WirelessMAN-SCa MS using the SBE to mitigate the effects of Doppler and multipath. These simulation results are for a 3 kph pedestrian MS for a 5 MHz bandwidth, 2.6 GHz channel defined by the Channel A and B impulse responses described for the Outdoor-to-Indoor & Pedestrian Test Environment in reference 2.

As just discussed, the SNR degradation at a velocity of 3 kph is the same as for stationary MS, i.e., the SBE performance is such that there is no Doppler SNR degradation at pedestrian speeds for WirelessMAN-SCa TDD burst intervals.

Table 4.2-1 indicates the SNR degradation due to the multipath created by the Channel A or Channel B CIR's is typically within 2 dB of the Es/No for a perfect AWGN channel. The SBE output does contain some residual ISI which for the simulation Es/No = 27 dB degrades the SNR ~2 dB which is in addition to the previously discussed ~1.5 dB residual ISI due to RX/TX filter implementation losses.

Table 4.2-1 SNR degradation of 3 kph Out-In & Ped Channel A & B relative to perfect channel.

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 kmph 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 performance.

Tables 4.2-2 and 4.2-3 give the QPSK/16-QAM/64-QAM link budgets for the Outdoor-to-Indoor & Pedestrian downlink and uplink, respectively. Figures 4.2-1 and 4.2-2 plot the RX SNR as a function of cell/sector radius for rate ½ QPSK. Based on these simulation results, a pedestrian WirelessMAN MS will experience ~2 dB SNR degradation relative to a perfect channel. The link budgets also include 2 dB cable/connector loss for the BS and an SC back-off advantage term for the MS UL TX based on reference 5.

The degraded Outdoor-to-Indoor DL QPSK cell size is 205 meters which is slightly less than twice the degraded Outdoor-to-Indoor UL QPSK cell size of 109 meters. The degraded Outdoor-to-Outdoor DL cell size is 848 meters which is slightly less than twice the degraded Outdoor-to-Outdoor UL cell size of 448 meters. Again, provided this evaluation is correct, this is a limitation of the existing WirelessMAN-SCa physical layer that needs to be addressed in the 802.16e project.

Table 4.2-2 Link budget for Outdoor-to-Indoor & Pedestrian DL

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 kmph Out-to-In & Ped Chan A/B SNR Degradation (ΔSNR_M)	2 dB [1]	
Cell Radius for Indoor 3 kmph Ped Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	205 150 114 m
Cell Radius for Outdoor 3 kmph Ped Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	848 615 468 m

[1] Based on SBE simulations.

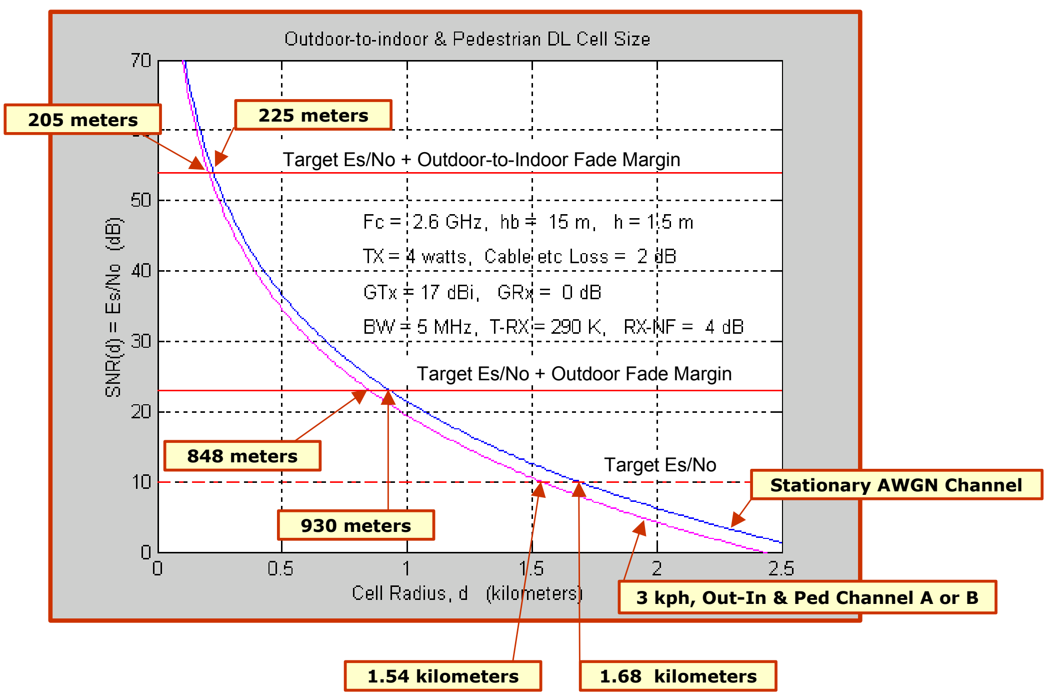


Figure 4.2-1 Outdoor-to-Indoor & Pedestrian DL cell size (2.6 GHz, 5 MHz BW, rate ½ QPSK) .

Table 4.2-3 Link budget for Outdoor-to-Indoor & Pedestrian UL

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 kmph Out-to-In & Ped Chan A/B SNR Degradation (ΔSNR_M)	2 dB[2]	
Cell Radius for Indoor Ped w 3 kmph Channel A/B	Invert PL(d) for SUI Terrain Type B (PE8)	109 72 53 m
Cell Radius for Outdoor Ped w 3 kmph 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.

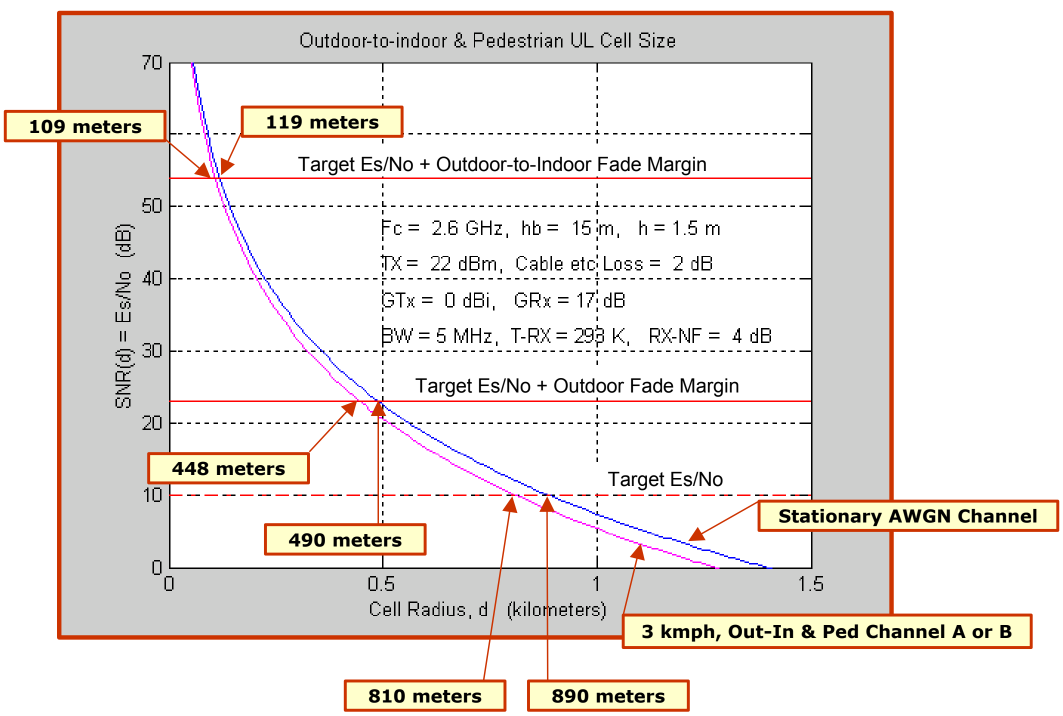


Figure 4.2-2 Outdoor-to-Indoor & Pedestrian UL cell size (2.6 GHz, 5 MHz BW, rate ½ QPSK) .

4.3 Indoor Office Test Environment (PE7 & PE14)

Table 4.3-1 summarizes the "indoor office" link performance for WirelessMAN-SCa MS using the SBE to mitigate the effects of Doppler and multipath. These simulation results are for a 3 kph pedestrian MS for a 5 MHz bandwidth, 2.6 GHz channel defined by the Channel A and B impulse responses described for the Indoor Office Test Environment in reference 2.

Table 4.3-1 indicates the SNR degradation due to the multipath created by the test CIR is typically within 2 dB of the Es/No for a perfect AWGN channel. The SBE output for the Indoor Office CIR's does contain a higher amount of residual ISI than for the Outdoor-to-Indoor & Pedestrian CIR's. At the simulation Es/No = 27 dB the residual ISI degrades the SNR ~3.5 dB in addition to the previously discussed ~1.5 dB residual ISI due to RX/TX filter implementation losses.

Table 4.3-1 SNR degradation of 3 kph Indoor Office Channel A & B relative to perfect channel.

Es/No (dB)	3 kilometers per hour Channel A	3 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.

Tables 4.3-2 and 4.3-3 give the QPSK/16-QAM/64-QAM link budgets for the Indoor Office downlink and uplink, respectively. Figures 4.3-1 and 4.3-2 plot the RX SNR as a function of cell/sector radius for rate ½ QPSK. Based on these simulation results, a WirelessMAN MS at a pedestrian velocity of 3 kph will experience ~2 dB SNR degradation relative to a perfect channel. The link budget also includes an SC back-off advantage term for the MS UL TX based on reference 5.

The degraded Indoor Office DL cell size is 19 meters. The degraded Indoor Office UL cell size of 13 meters.

Table 4.3-2 Link budget for Indoor Office DL

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 kmph Indoor Office Channel A/B SNR Degradation (ΔSNR_M)	2 dB [2]	
Cell Radius for 3 kmph 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.

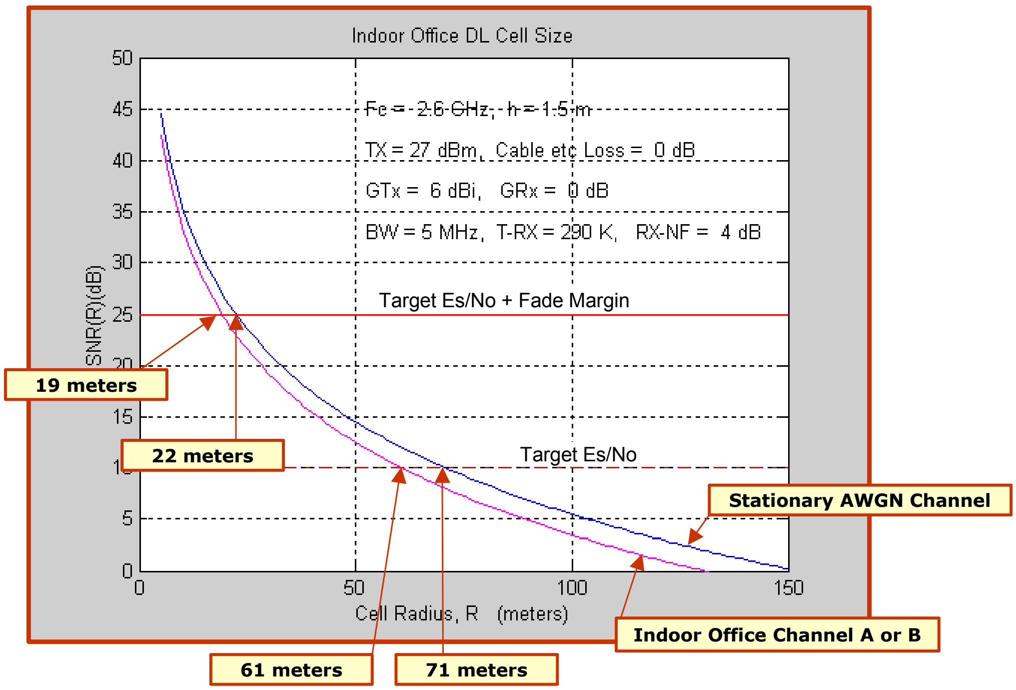


Figure 4.3-1 Indoor Office DL cell size (n = 2 floors).

Table 4.3-2 Link budget for Indoor Office UL

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 kmph Indoor Office Channel A/B SNR Degradation (ΔSNR_M)	2 dB [3]	
Cell Radius for 3 kmph 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.

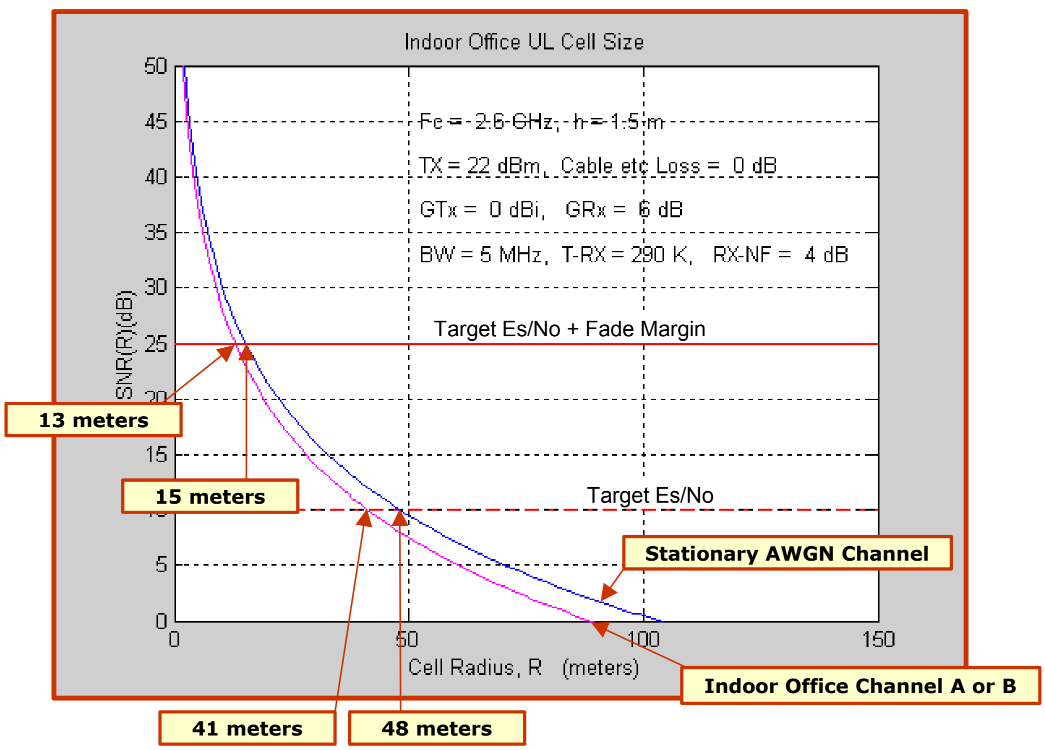


Figure 4.3-2 Indoor Office UL cell size (n = 2 floors).

4.4 Ranging, Power Control and Time Synchronization, (PE26, PE27, PE25)

In the WirelessMAN-SCa terminology, the burst preamble nominally contains m sequential Unique Words each of which is a so-called CAZAC (constant amplitude, zero autocorrelation) sequence of complex numbers. The CAZAC preamble is exploited in the signal processing associated with Downlink Acquisition (by the MS and SS) and Uplink Ranging (by the BS with direction to the MS and SS). These CAZAC signal processing techniques can operate on a single burst basis and provide time synchronization, carrier offset estimate, and an accurate amplitude estimate.

As diagramed in Figure 2-1, a timing recovery process precedes the SBE processing. Residual timing error is mitigated by a feed forward timing error determination/interpolation/decimation function in the baseband RX. The timing recovery is accomplished with the "squaring and summing" algorithm from Oerder and Meyr (reference 6). Analysis from reference 7 indicates that the accuracy of the O&M timing recovery algorithm is such that the timing error of the 1/T rate data input to the SBE is on the order of +/-T/32 for reasonable signal strengths (Es/No > 6 dB) and integration times (128 symbols). The data is simply delayed until the timing offset and interpolation/decimation control parameters are available.

The SBE uses the CAZAC based amplitude estimate to scale the data input to the FFE such that it agrees with the symbol scale that is input to the FBE. During the operation of the DFE (once the coefficients are available) decision aided gain control and decision aided carrier phase recovery adjust the output of the FFE filter to compensate for residual amplitude variation and residual carrier offset.

In short, the MS SBE processing extracts the timing and amplitude parameters from the DL signal. The BS SBE processing extracts these same parameters for the UL signal. In both cases, the extraction is complete for individual bursts.

The primary difference between a moving MS and a stationary SS from the BS viewpoint is that the MS requires frequent adjustment of the Ranging parameters. Since the SBE measures the Ranging parameters for each processed burst and since they are frequently changing it is not necessary or desirable for the BS to formally put the MS into "Ranging". The BS simply tells the MS to adjust its timing and amplitude whenever it is necessary by sending the MS a RNG-RESP message.

4.5 Channel Coding and Impact on Fixed SS (PE21, PE22)

The above link budget analysis indicates the UL range is only half the DL range. A straightforward enhancement to the WirelessMAN-SCa to remedy this is to include a PN spreading/despreading function in the physical layer (personal communication with Dr. Brian Eidson). This will be assessed and, if favorably concluded, proposed in a future contribution.

The insertion of additional Pilot Words for the BS-MS link has no impact on Fixed Station WirelessMAN-SCa unless the insertion of additional Pilot Words is considered to be change the robustness of the modulation/encoding. The question is whether rate ½ QPSK with additional Pilot Words is to be considered more robust than rate ½ QPSK without additional Pilot Words. This may be a discussion item but will likely be superceded by a PN spreading proposal.

4.6 Proposal Evaluation Criteria Not Addressed

As stated earlier no results are available for proposal evaluation criteria PE10, PE11, PE12, PE17, PE18 and PE19 since these criteria require system level simulations of specific deployment scenarios that are beyond our current capabilities. Additionally, no results are available for PE23, "power savings in active and standby modes".

5 Conclusion

This proposal describes how the existing WirelessMAN-SCa physical layer specification is adequate for the deployment of mobile subscriber stations (MS) – in terms of mitigating the effects of multipath channels and vehicular rate Doppler. This is a direct consequence of the ability to give the WirelessMAN-SCa MS receiver the same single burst equalization (SBE) technology used in high performance WirelessMAN-SCa base stations (BS). The BS uses a real time SBE to provide high performance multiple subscriber / multipath reception. Both the MS and the BS can use the real time SBE to be robust with respect to multipath and Doppler. The fixed subscriber station (SS) does not need a real time SBE although it certainly may have one.

The link budget analysis, however, indicates a range asymmetry between the downlink (DL) and uplink (UL). The DL range is approximately twice the UL range for same modulation/encoding level. This suggests enhancements to the WirelessMAN-SCa physical layer are necessary to increase the range of the UL. A straightforward enhancement to the WirelessMAN-SCa to remedy the DL/UL asymmetry is to include a PN spreading/despreading function in the physical layer to extend the range of the MS UL. This will be the subject of a future contribution to the IEEE Project 802.16e.

References

1. Naofal Al-Dhahir & John M. Cioffi, “Fast Computation of Channel-Estimate Based Equalizers in Packet Data Transmissions”, IEEE Transactions on Signal Processing, pp. 2462-2473, 11, 43 (Nov. 1995).
2. ETSI TR 101 112 V.3.2.0, “Selection procedures for the choice of radio transmission technologies for UMTS”, ETSI Technical Report, 04-1998.
3. IEEE 802.16e-03/01, “Mobile System and Proposal Evaluation Requirements”, 2003-01-16.
4. IEEE 802.16c-01/29r4, “Channel Models for Fixed Wireless Applications”, 2001-07-16.
5. IEEE 802.16c-01/46, “Analysis of PHY waveform peak to mean ratio and impact on RF amplification”, 2001-03-09.
6. M.Oerder and H. Meyr, “Digital Filter and Square Timing Recovery”, IEEE Trans. Commun. COM-36, 605-611, May 1988.
7. U. Mengali and A.N. D’Andrea, “Synchronization Techniques for Digital Receivers”, Plenum Press, N.Y., 1997.

6 Abbreviations

AWGN = additive white Gaussian noise
BS = base station
CAZAC = constant amplitude zero autocorrelation
CIR = channel impulse response
DFE = decision feedback equalizer
DL = downlink
FBE = feedback equalization
FFE = feed forward equalization
Kph = kilometers per hour
MAC = media access control
ML = maximum likelihood
MMSE = minimum mean square error (estimate)
MS = mobile subscriber (station)
NLOS = non-line-of-sight
OFDM = orthogonal frequency division multiplexing
OFDMA = orthogonal frequency division multiple access
PHY = physical layer
PN = pseudo random
SBE = single burst equalization
RX = receive
SC = single carrier
SS = (fixed) subscriber station
TDD = time division duplex
TX = transmit
UL = uplink