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| Title | **802.16e Proposal: Link Performance of WirelessMAN-SCa Mobile Subscriber Stations** |
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| 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. |
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# 802.16e Proposal: Link Performance of WirelessMAN-SCa Mobile Subscriber Stations

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## 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 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 same modulation/encoding level, say rate _ 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.

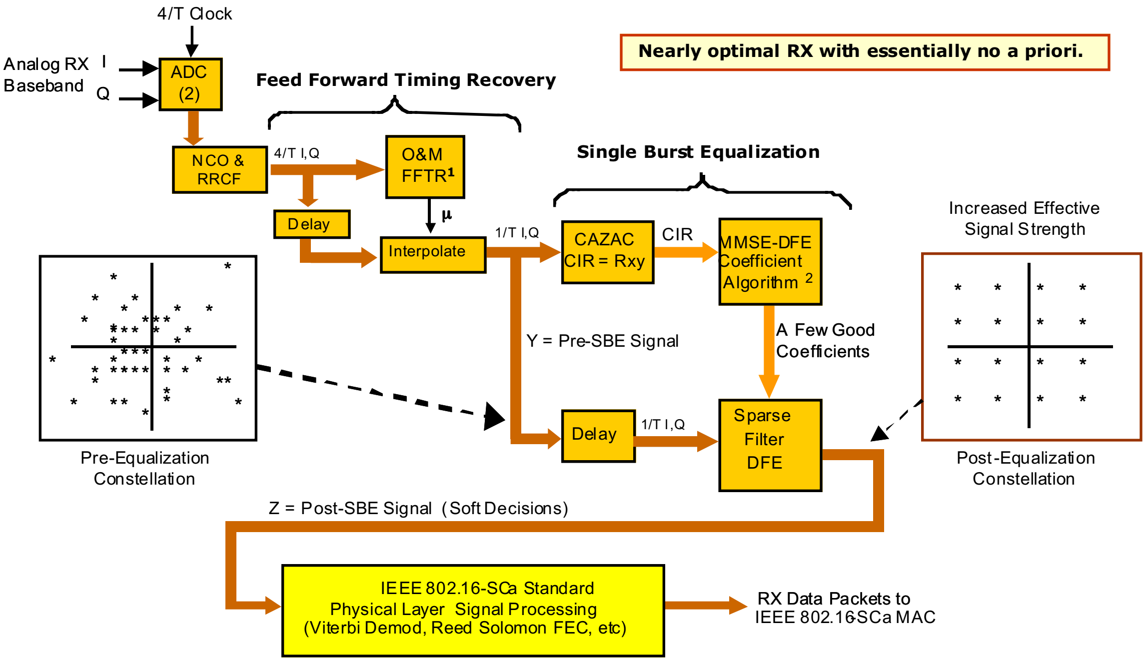
Although a specific SBE technology is presented herein, “SBE” for these purposes can be considered a generic solution to the BS multiple subscriber, multipath reception problem. Thus, any alternative receiver technologies or methods that solve the multipoint-to-point, short burst, multipath receiver 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 either the FFE or FBE filters.

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 2-3. 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.

The 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

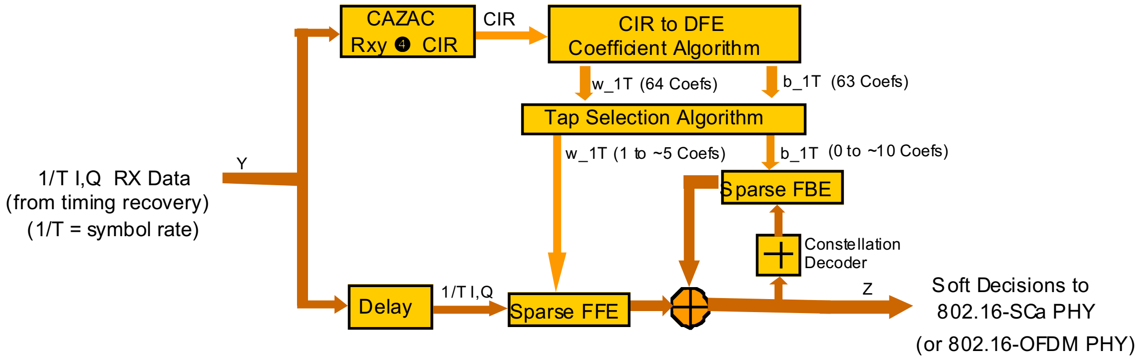


Figure 2-2 SBE consisting of CIR estimate, MMSE-DFE / Tap Selection and sparse DFE.

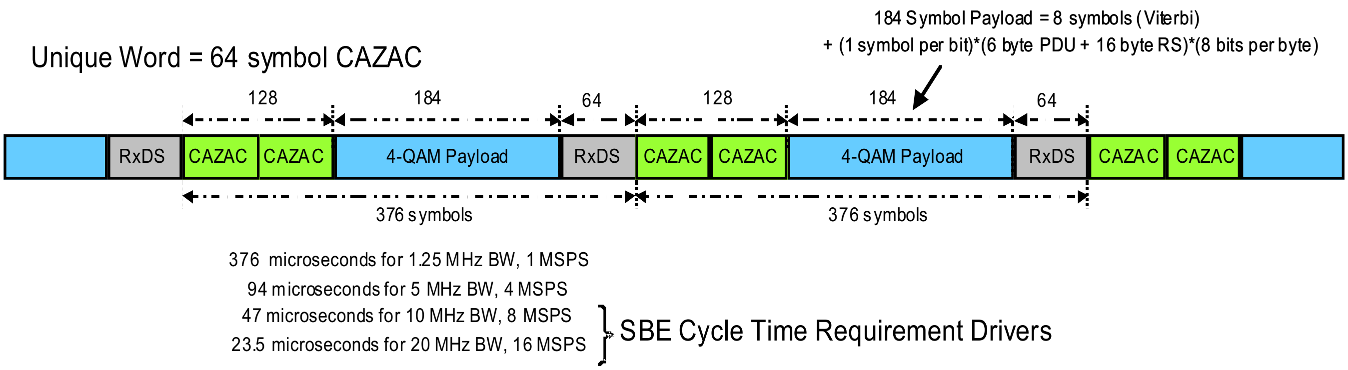


Figure 2-3 SBE cycle time requirement based on a BW-REQ message stream to a WirelessMAN-SCa BS.

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 can exhibit superior link performance when compared to other WirelessMAN systems without SBE. For WirelessMAN-OFDM and WirelessMAN-OFDMA this is due to the DFE based SBE preventing the loss of channel capacity that is otherwise associated with severe multipath spectral fades. Figure 2-4 illustrates this point with the power spectra of pre-SBE and post-SBE signals for the ETSI Vehicular Test Environment Channel A (reference 2).

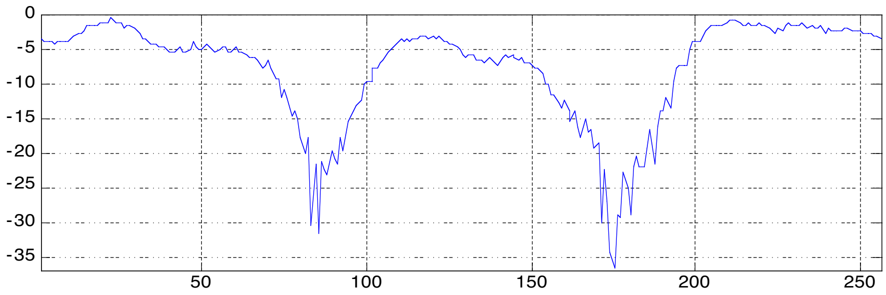


Figure 2-4 Power spectra of pre-SBE and post-SBE signals for ETSI Vehicular Test Channel A.

# 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.

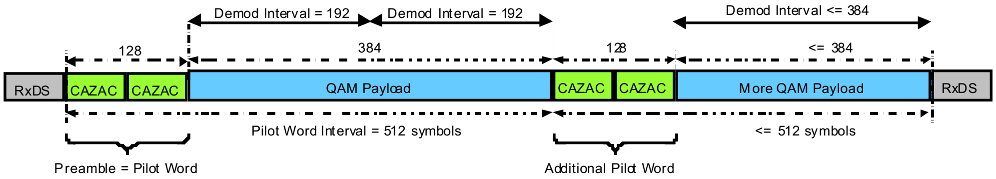
For any channel changes, due to Doppler or otherwise, that are slow compared to the duration of the received burst, the channel is nearly stationary during the burst. This provides that FFE and FBE filter coefficients in the MMSE-DFE can remain static for the duration of the burst. Decision aided carrier 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 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 Demod Interval.

(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).

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, and would express this 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 (kmph)** | **1.25 MHz BW** | **5 MHz BW** | **10 MHz BW** | **20 MHz BW** |
|---|---|---|---|---|
| **3** | **not required** | **not required** | **not required** | **not required** |
| **38** | **256 (11%)**[2] | **1024 (11%)**[3] | **2048 (6%)**[3] | **4096 (3%)**[3] |
| **75** | **128 (20%)** | **512 (20%)** | **1024 (11%)** | **2048 (6%)** |
| **150** | **64 (33%)** | **256 (33%)** | **512 (20%)** | **1024 (11%)** |

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.

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 kmph in a 5 MHz WirelessMAN-SCa system should be operating with a Pilot Word Interval of 512 symbols. This introduces an additional overhead of 20% 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 20% 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 a 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)

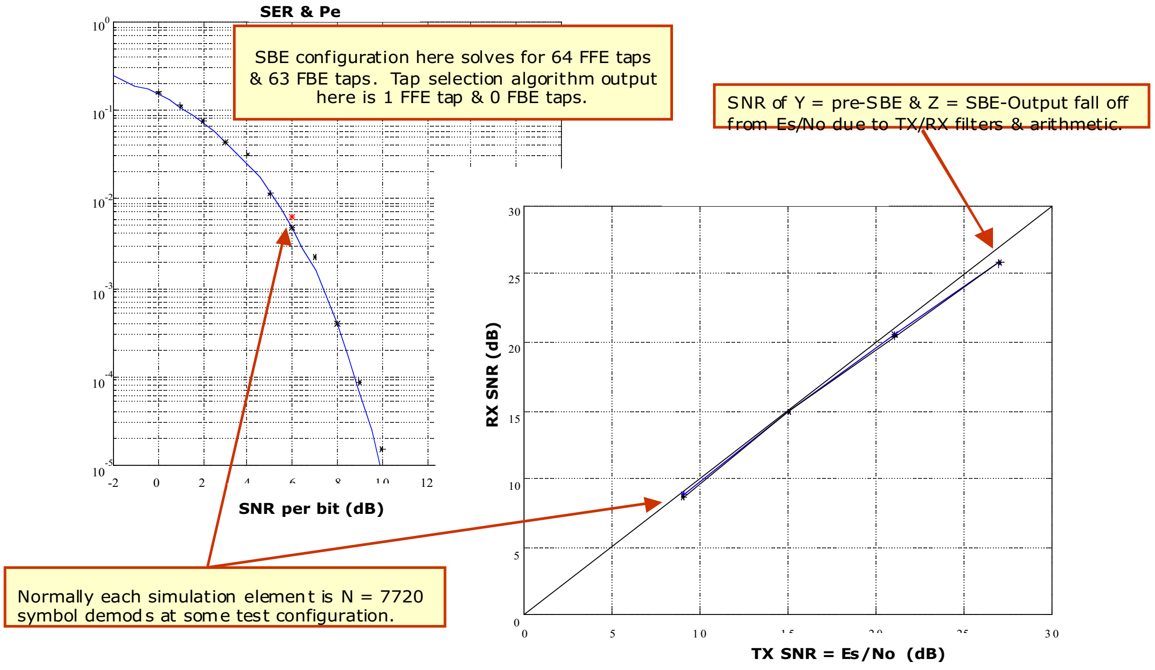
| Modulation / Encoding | Target Es/No (ahead of decoding) |
|---|---|
| QPSK / rate ? | 10 dB |
| 16-QAM / rate ? | 17 dB |
| 64-QAM / rate ? (?) | 23 dB |

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.

Figures 4-1 and 4-2 show control results for the 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, the measured SER agrees with the theoretical QPSK error probability and the post-SBE RX SNR agrees with the TX SNR = Es/No. Figure 4-1 also shows a 1 to 2 dB implementation loss at high SNR that is evident in both the input, Y, and the output, Z, of the SBE. This is mostly due to the finite filters in the RX and TX chain.

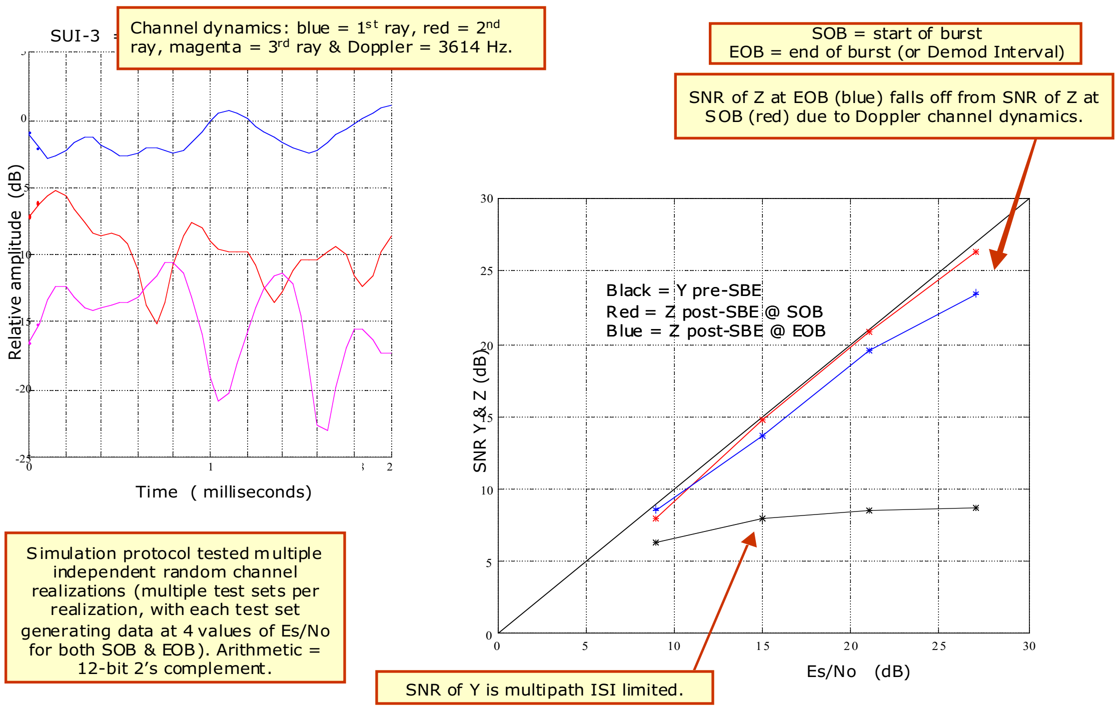


SBE configuration here solves for 64 FFE taps & 63 FBE taps. Tap selection algorithm output here is 1 FFE tap & 0 FBE taps.

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.

Figure 4-1 SBE link simulation: perfect channel-AWGN-QPSK control.



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

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.

Figure 4-2 SBE link simulation: MS velocity = 150 kmph, SUI-3 channel- AWGN-QPSK control.

Figure 4-2 shows an example 4 Es/No trial for an MS with a 150 kmph 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 the start of burst (SOB, in red) and at the end of burst (EOB, in blue). The blue SNR(Z|EOB) shows Doppler degradation at the trial's 256 symbol or 64 microsecond Demod Interval. The Doppler degradation results from a mismatch between SBE DFE coefficients and the RX signal at the trial Demod Interval of 256 symbols (the simulation EOB).

## *4.1 Vehicular Test Environment (PE9 & PE16)*

Tables 4.1-1 to 4.1-3 summarize the vehicular link performance for QPSK/16-QAM/64-QAM 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. Results given here are for velocities of 3, 75 and 150 kilometers per hour.

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 Pilot Word Interval for these results is 512 symbols. If a Pilot Word Interval of 256 is used, the SNR degradation for the 150 kmph column would be reduced to that of the 75 kmph column.

As anticipated, there is no SNR degradation for a 3 kmph MS compared to a stationary MS. The 3 kmph velocity corresponds to only a 73 Hz Doppler frequency – the CIR coefficients are essentially stationary over any reasonable TDD burst duration, say < 2 milliseconds or 4000 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

| Es/No (dB) | 3 kilometers per hour | 75 kilometers per hour | 150 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.**

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

| Es/No (dB) | 3 kilometers per hour | 75 kilometers per hour | 150 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 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 _ QPSK. Based on these simulation results, a WirelessMAN MS at a velocity of 75 kmph 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 cell size is 2.3 kilometers which is slightly more than twice the degraded Vehicular UL cell size of 1.1 kilometers. This is clearly a limitation of the existing WirelessMAN-SCa system 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 ($\Delta PL_h$) | 1.5 meters (PE9) = -.8 dB [1] | |
| RF Frequency ($\Delta PL_f$) | 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 ($\Delta SNR_{75}$) | 2 dB [2] | |
| Allowed Path Loss PL(d) for 75 kmph Vehicular Channel A/B | Required SNR + $\Delta SNR_{75}$ – 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.

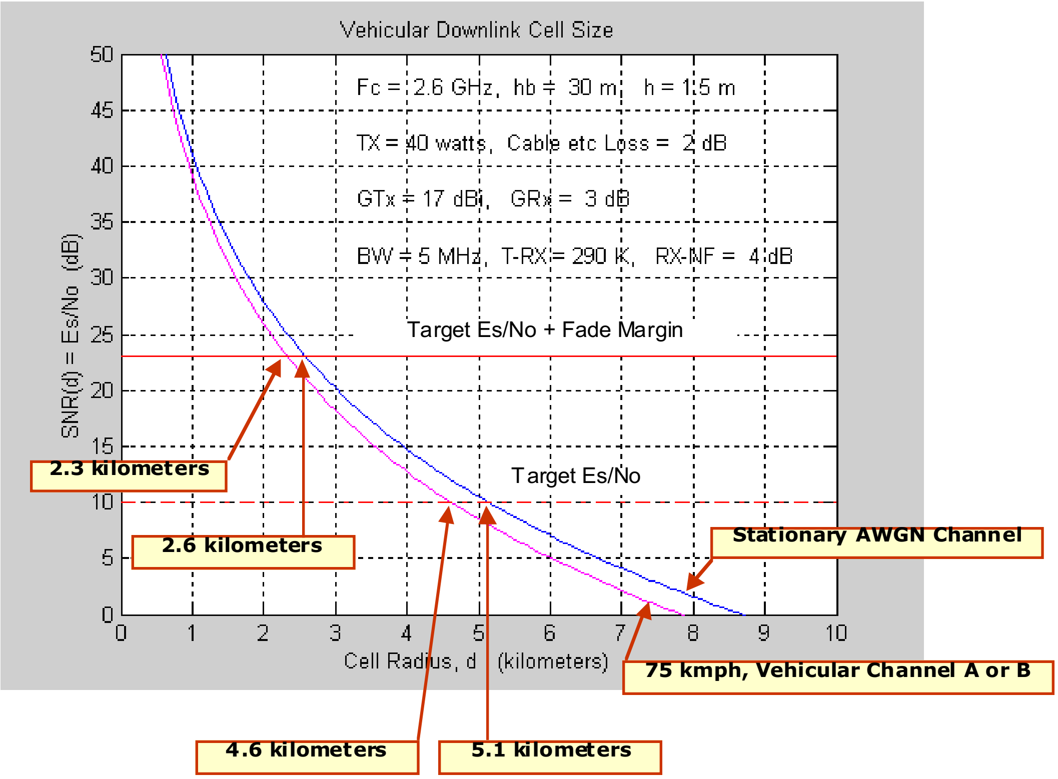


Figure 4.1-1 Vehicular DL cell size (2.6 GHz, 5 MHz BW, rate _ QPSK) .

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) ( $\Delta PL_h$) | 1.5 meters (PE9), $\Delta PL_h$ = -.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 ($\Delta PL_f$) | 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 ( $\Delta SNR_{75}$) | 2 dB [2] | |
| Allowed Path Loss PL(d) for 75 kmph Vehicular Channel A | Required SNR + $\Delta SNR_{75}$ – 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.

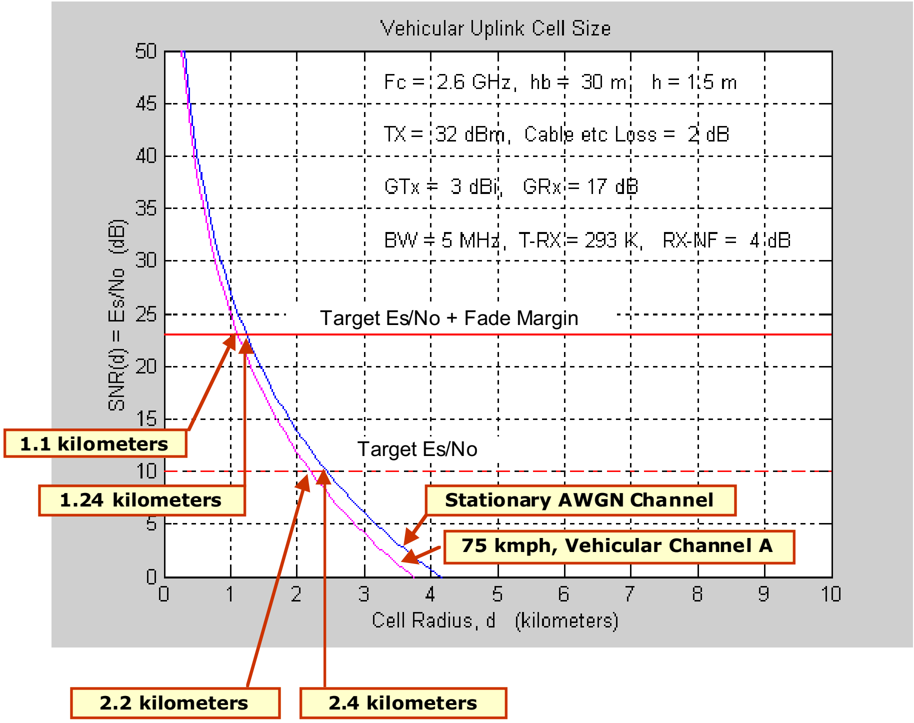


Figure 4.1-2 Vehicular UL cell size (2.6 GHz, 5 MHz BW, rate _ QPSK) .

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

Table 4.2-1 summarizes the “outdoor-to-indoor & pedestrian” link performance for QPSK/16-QAM/64-QAM WirelessMAN-SCa MS using the SBE to mitigate the effects of Doppler and multipath. These simulation results are for a 3 kmph 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 kmph 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 reasonable SC 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 previously discussed ~1.5 dB residual ISI due to RX/TX filter implementation losses.

Table 4.2-1 SNR degradation of 3 kmph 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 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 _ QPSK. Based on these simulation results, a WirelessMAN MS at a pedestrian velocity of 3 kmph 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 cell size is 205 meters which is slightly less than twice the degraded Outdoor-to-Indoor UL 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 system 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 ($\Delta PL_h$) | 1.5 meters (PE8) = -.8 dB | |
| RF Frequency ($\Delta PL_f$) | 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 ($\Delta SNR_M$) | 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.

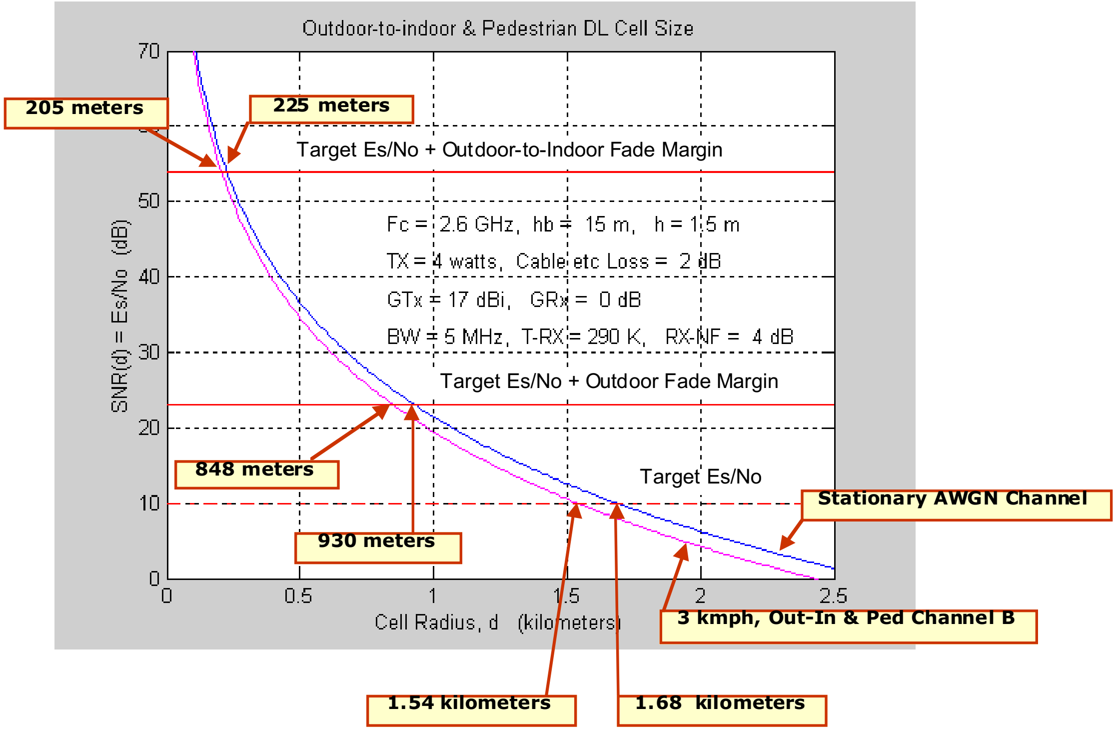


Figure 4.2-1 Outdoor-to-Indoor & Pedestrian DL cell size (2.6 GHz, 5 MHz BW, rate _ QPSK) .

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) ($\Delta PL_h$) | 1.5 meters (PE8), $\Delta PL_h$ = -.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 ($\Delta PL_h$) | 1.5 meters (PE8) = -.8 dB | |
| RF Frequency ($\Delta PL_f$) | 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 ($\Delta SNR_M$) | 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.

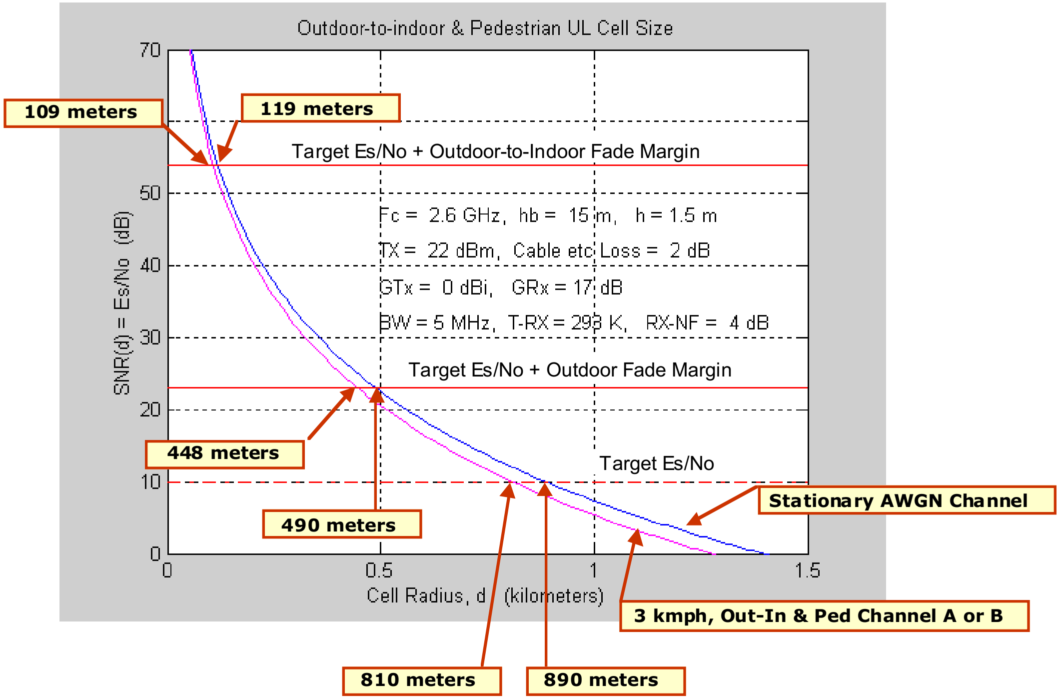


Figure 4.2-2 Outdoor-to-Indoor & Pedestrian UL cell size (2.6 GHz, 5 MHz BW, rate _ QPSK) .

## 4.3 Indoor Office Test Environment (PE7 & PE14)

Table 4.3-1 summarizes the “indoor office” link performance for QPSK/16-QAM/64-QAM WirelessMAN-SCa MS using the SBE to mitigate the effects of Doppler and multipath. These simulation results are for a 3 kmph 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 kmph 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 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 _ QPSK. Based on these simulation results, a WirelessMAN MS at a pedestrian velocity of 3 kmph will experience ~2 dB SNR degradation relative to a perfect channel. The link budget 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 ($\Delta SNR_M$) | 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.

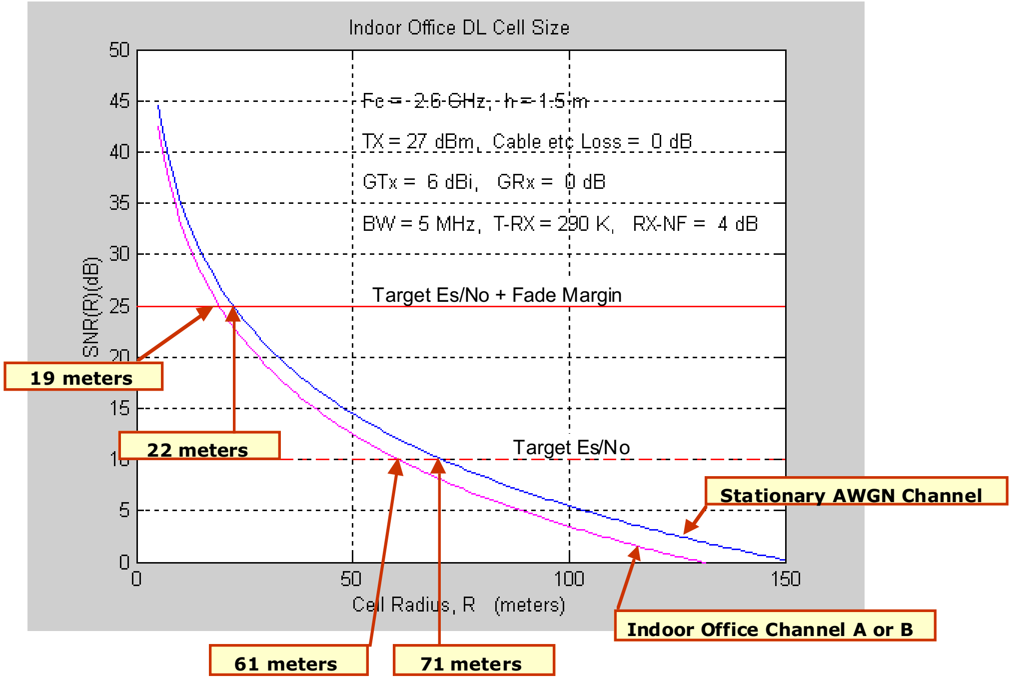


Figure 4.3-1 Indoor Office DL cell size (n = 2 floors).

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 ($\Delta SNR_M$) | 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.

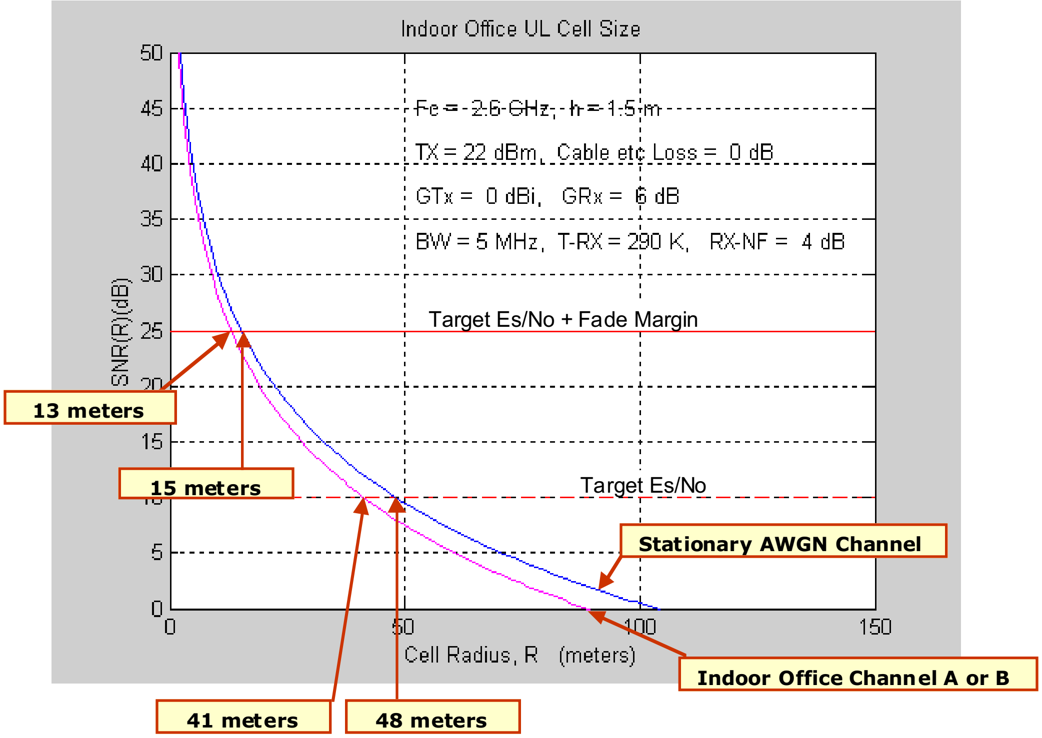


Figure 4.3-2 Indoor Office UL cell size (n = 2 floors).

## 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/dispreading 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 _ QPSK with additional Pilot Words is to be considered more robust than rate _ 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/dispreading 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

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## 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 (filter)
FFE = feed forward equalization (filter)
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
TX = transmit
UL = uplink