**Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)**

**Submission Title:** [**Two Hopeful Technologies for TG4a --- DS-UWB and CS-UWB**]

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**Re:** [ ]

**Abstract [**This document has been prepared for an official proposal in January 2005. Two possible technologies of direct-sequence UWB(DS-UWB) and chirp-signal UWB(CS-UWB) are investigated in performance on BER, ranging resolution, complexity, power consumption, SOP and so on. The performance comparison is concluded by a few differences in performance but we need to modify these primitive technologies so as to match with requirements. ]

**Purpose:** [Providing technical contributions to IEEE 802.15.4a. ]

# Two Hopeful Technologies for TG4a
# --- DS-UWB and CS-UWB

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# Outline of presentation

- Requirements of TG4a
- DS-UWB and CS-UWB (Chirp signal UWB)
  - ✓ Advantages of using DS-UWB and CS-UWB
  - ✓ Correlation characteristics
  - ✓ Coexistence
  - ✓ Frequency bandwidth
  - ✓ Link budget
  - ✓ Performance examples
  - ✓ Ranging issue
  - ✓ Summary and comparison
- Conclusion

# Technical Requirements

- Low complexity, low cost, and low power consumption.
- Precision ranging by PHY --- tens of centimeters.
- Communication distance is ~30m (can be extended)
- Better robustness and mobility than 802.15.4
- Low bit rate (individual link) >= 1 kbps.
- High bit rate (aggregated) >= 1 Mbps.

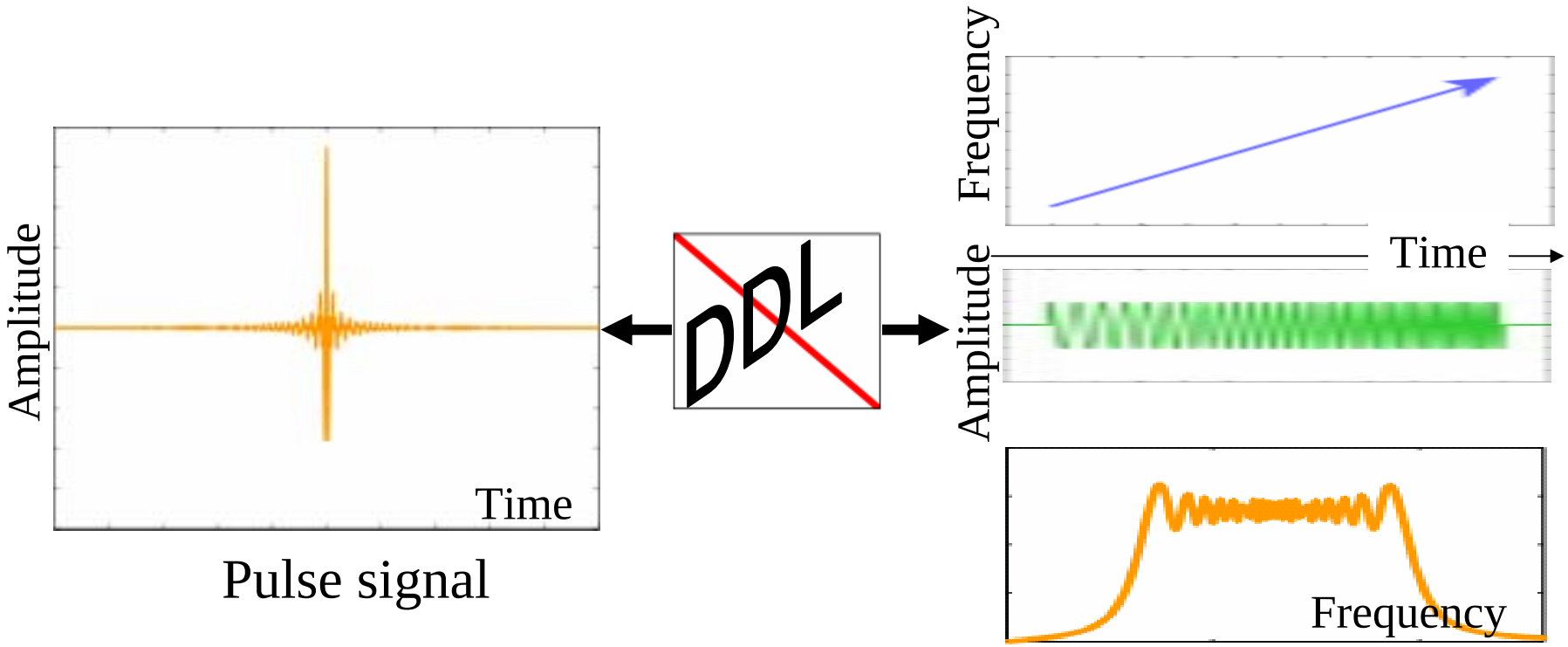
# Advantages

Both DS-UWB and CS-UWB are available for

- **High precision ranging**
  - Be up to tens of centimeters
  - Depend on pulse width (bandwidth)
- **Low complexity**
  - Simple ADC (2 or 3-bit)
- **High frequency efficiency**
  - Uniform use of frequency within the band.
- **High robustness against noise and multipath**
  - Correlated processing
- **Low power consumption**
  -

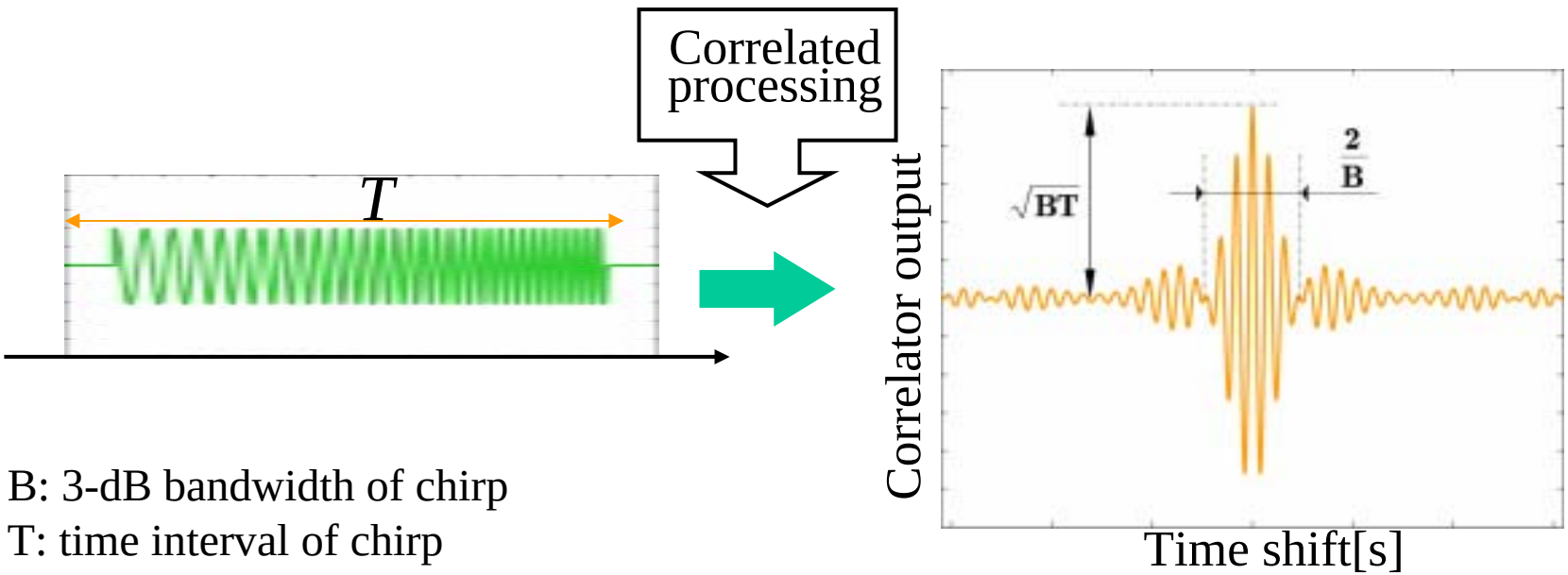
# Generation of CS-UWB

- CS-UWB can be generated by passing a pulse signal through a distributed delay line (DDL) such as a SAW DDL.



# Correlated processing

- Correlated processing produces not only high precision ranging but also robustness against noise and multipath.

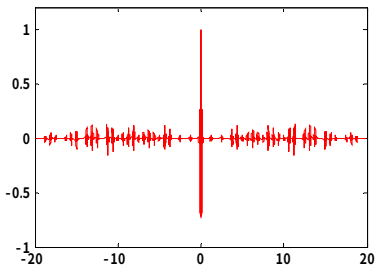



B: 3-dB bandwidth of chirp
T: time interval of chirp

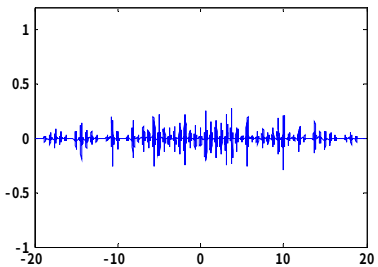
The wide the bandwidth, the sharp the peak.

# Characteristics of correlation

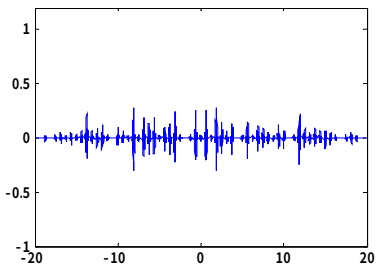
DS-UWB



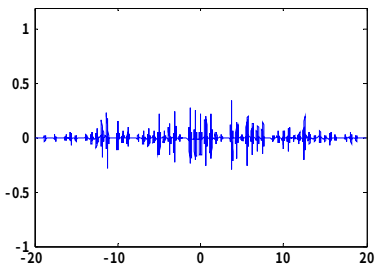

autocorrelation




cross correlation

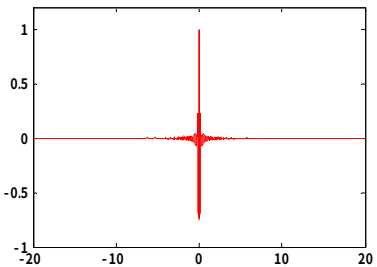



cross correlation

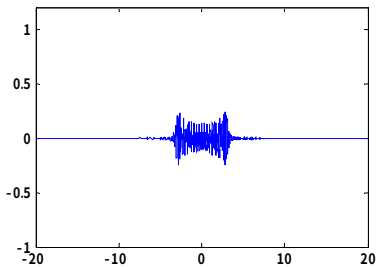



cross correlation

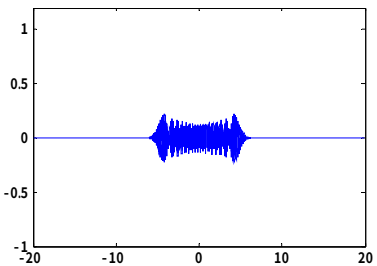
CS-UWB



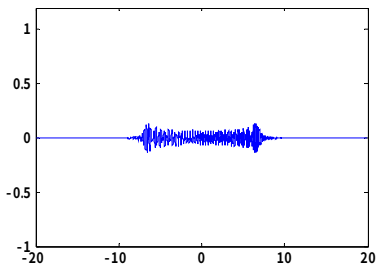

autocorrelation




cross correlation

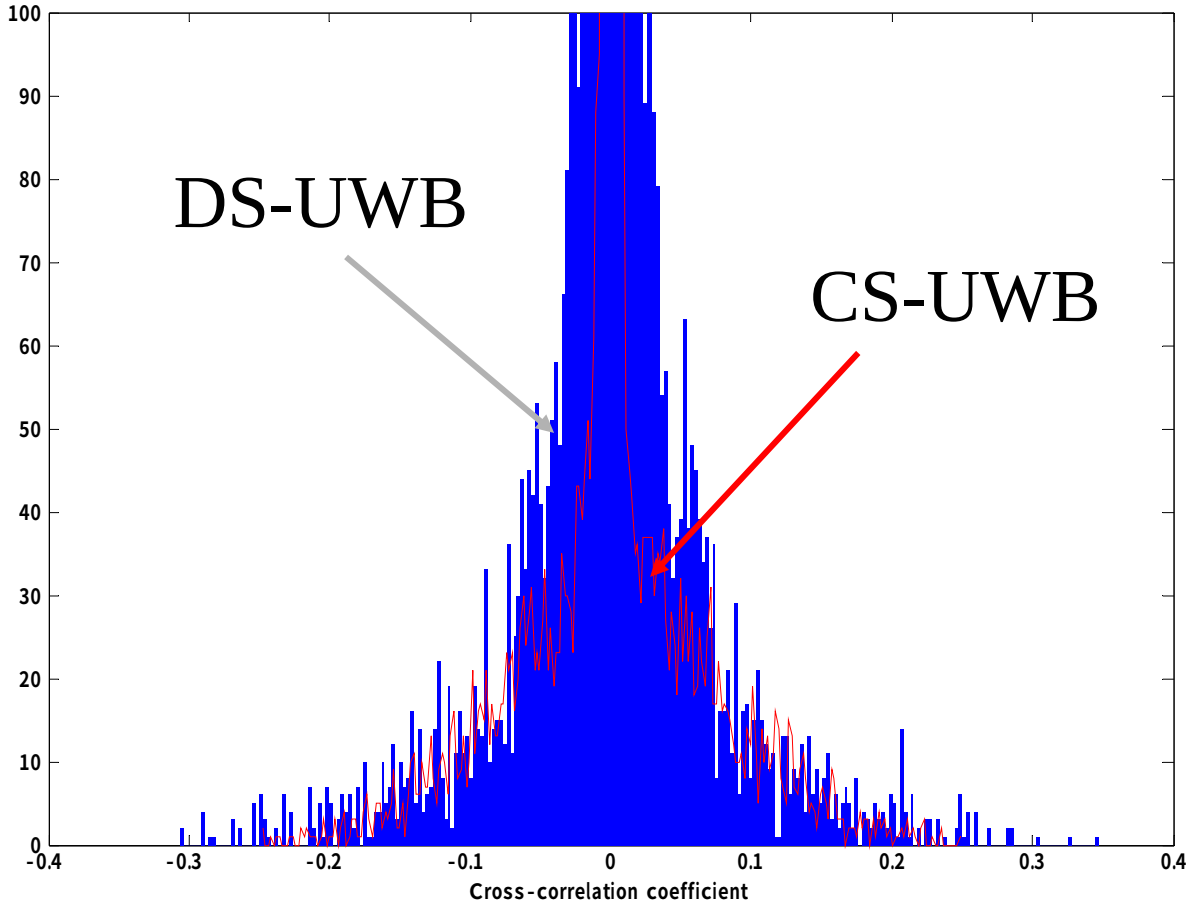



cross correlation



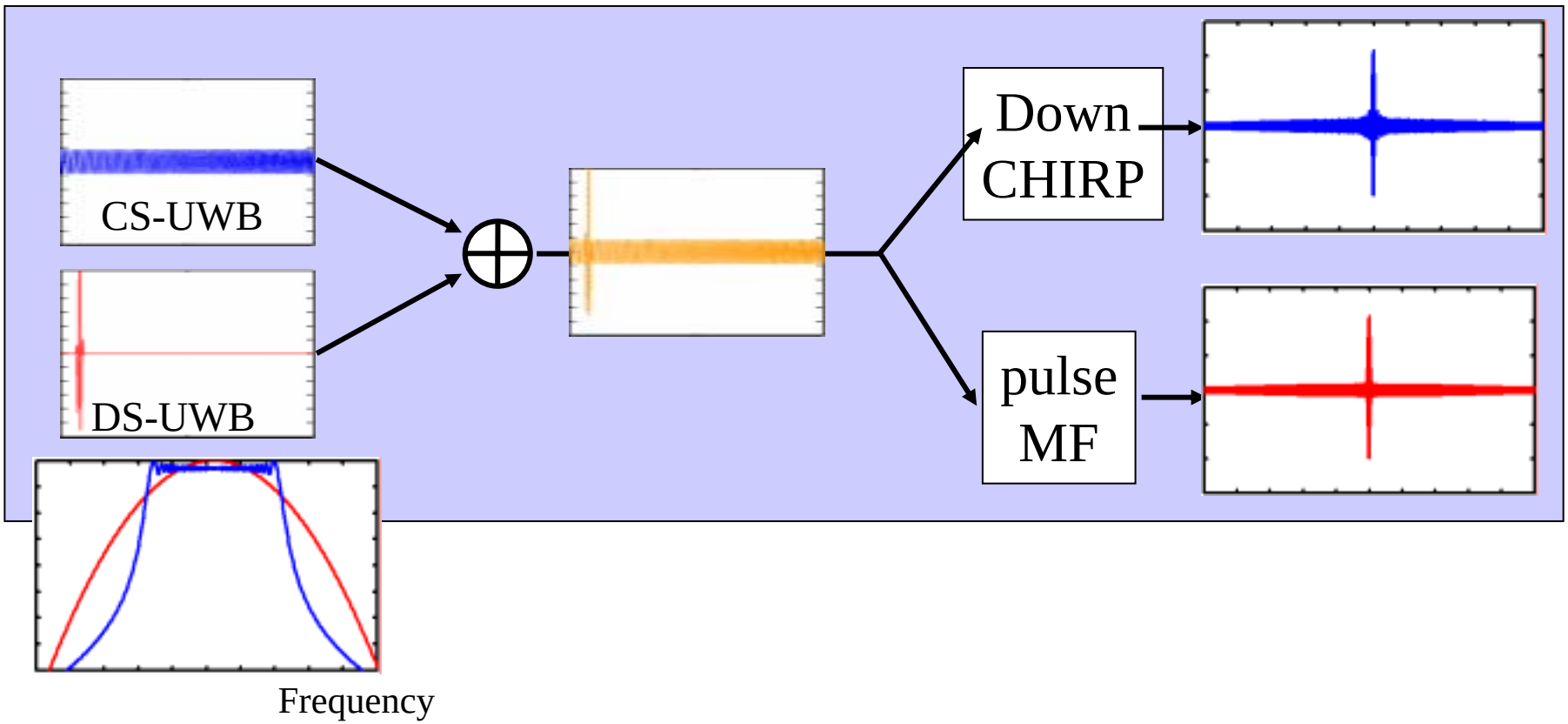

cross correlation

# Cross correlation coefficient

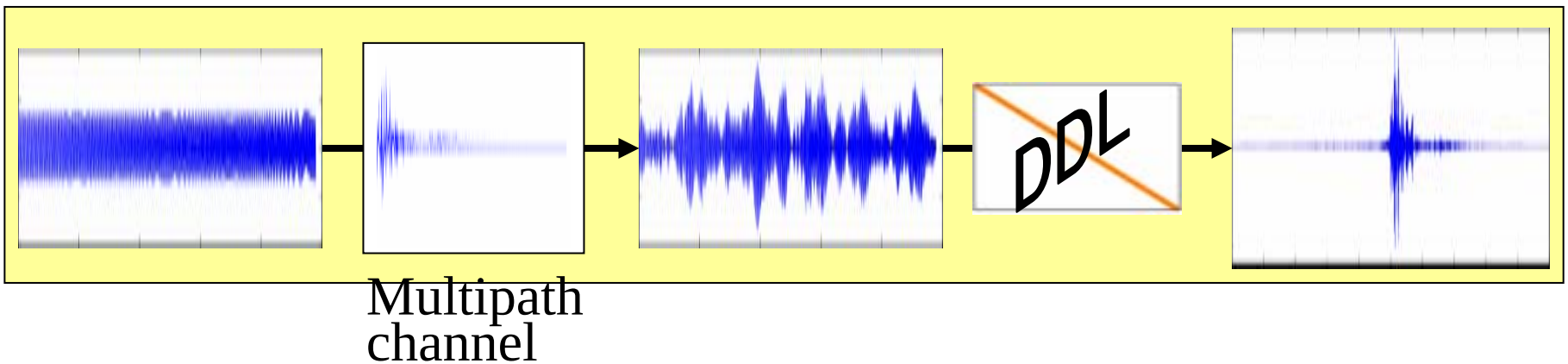


# Coexistence

- Coexistence between DS-UWB and CS-UWB



# Robustness against multipath



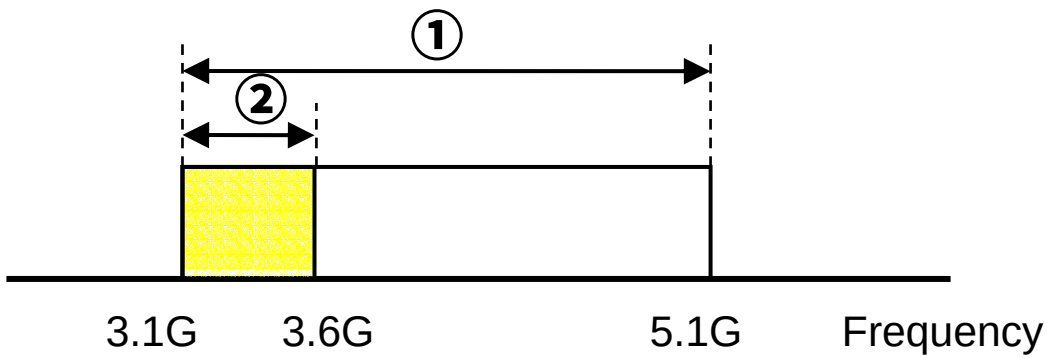

**Due to the good correlation characteristics, correlator can detect a signal even under heavy multipath channel.**

# Frequency Band

- We consider the use of UWB band here, and give examples of link budgets for use of the following two bandwidth.

① BW=2 GHz (3.1GHz – 5.1GHz)

② BW=500 MHz (3.1GHz – 3.6GHz)



# DS-UWB Link Budget (BW=2GHz)

| Parameter | Value | Value | Notes |
|---|---|---|---|
| Data rate (Rb) | 1 | 1024 | (kbps) |
| Modulation | BPSK | | Coherent detection |
| Coding rate (R) | ½ | | (24,12)-Extended Golay Hard-decision decoding |
| Raw Symbol rate (Rs) | 2 | 2048 | Rs=Rb/R (ksymbol/second) |
| Pulse duration (Tp) | 0.662 | | (ns) |
| Spreading code length (Ns) | 1024 | 64 | |
| Chip rate (Rc) | 2.048 | 131.072 | =Rs*Ns (MHz) |
| Chip duration | 488.3 | 7.63 | =1/Rc (nsec) |

| Parameter | Value | Value | Unit |
|---|---|---|---|
| Distance (d) | 30 | 10 | m |
| Peak payload bit rate (Rb) | 1 | 1024 | kbps |
| Average Tx power (Pt) | -10.5 | | dBm |
| Tx antenna gain (Gt) | -3.00 | | dBi |
| Frequency Band | 3.1 - 5.1 | | GHz |
| Geometric center frequency (fc) | 3.98 | | GHz |
| Path loss @ 1m (L1) | 44.43 | | dB |
| Path loss @ d m (Ld) | 29.54 | 20.00 | dB |
| Rx antenna gain (Gr) | -3.00 | | dBi |
| Rx power (Pr) | -90.47 | -80.93 | dBm |
| Average noise power per bit (N) | -144.00 | -113.90 | dBm |
| Rx Noise Figure (Nf) | 7.00 | | dB |
| Average noise power per bit (Pn) | -137.00 | -106.90 | dBm |
| Minimum required Eb/N0 (S) | 6.25 | | dB |
| Implementation loss (I) | 3.00 | | dB |
| **Link Margin** | 37.28 | 16.72 | dB |
| **Min. Rx Sensitivity Level** | -127.75 | -97.65 | dBm |

# DS-UWB Link Budget (BW=500MHz)

| Parameter | Value | Value | Notes |
|---|---|---|---|
| Data rate (Rb) | 1 | 1024 | (kbps) |
| Modulation | BPSK | | Coherent detection |
| Coding rate (R) | ½ | | (24,12)-Extended Golay Hard-decision decoding |
| Raw Symbol rate (Rs) | 2 | 2048 | Rs=Rb/R (ksymbol/second) |
| Pulse duration (Tp) | 2.649 | 2.649 | (ns) |
| Spreading code length (Ns) | 1024 | 64 | |
| Chip rate (Rc) | 2.048 | 131.072 | =Rs*Ns (MHz) |
| Chip duration | 488.3 | 7.63 | =1/Rc (nsec) |

| Parameter | Value | Value | Unit |
|---|---|---|---|
| Distance (d) | 30 | 10 | m |
| Peak payload bit rate (Rb) | 1 | 1024 | kbps |
| Average Tx power (Pt) | -16.9 | | dBm |
| Tx antenna gain (Gt) | -3.00 | | dBi |
| Frequency band | 3.1 - 3.6 | | GHz |
| Geometric center frequency (fc) | 3.34 | | GHz |
| Path loss @ 1m (L1) | 42.92 | | dB |
| Path loss @ d m (Ld) | 29.54 | 20.00 | dB |
| Rx antenna gain (Gr) | -3.00 | | dBi |
| Rx power (Pr) | -95.36 | -85.82 | dBm |
| Average noise power per bit (N) | -144.00 | -113.90 | dBm |
| Rx Noise figure (Nf) | 7.00 | | dB |
| Average noise power per bit (Pn) | -137.00 | -106.90 | dBm |
| Minimum required Eb/N0 (S) | 6.25 | | dB |
| Implementation loss (I) | 3.00 | | dB |
| **Link Margin** | 32.39 | 11.83 | dB |
| **Min. Rx Sensitivity Level** | -127.75 | -97.65 | dBm |

# CS-UWB Link Budget (BW=2GHz)

| Parameter | Value | Value | Notes |
|---|---|---|---|
| Data rate (Rb) | 1 | 1024 | (kbps) |
| Modulation | BPSK | | Coherent detection |
| Coding rate (R) | ½ | | (24,12)-Extended Golay Hard-decision decoding |
| Raw Symbol rate (Rs) | 2 | 2048 | Rs=Rb/R (ksymbol/s) |
| Chirp signal duration (Tc) | 100 | | (ns) |
| Spreading code length (Ns) | 1024 | 4 | |
| Chip rate (Rc) | 2.048 | 8.192 | =Rs*Ns (MHz) |
| Chip duration | 488.3 | 122.1 | =1/Rc (nsec) |

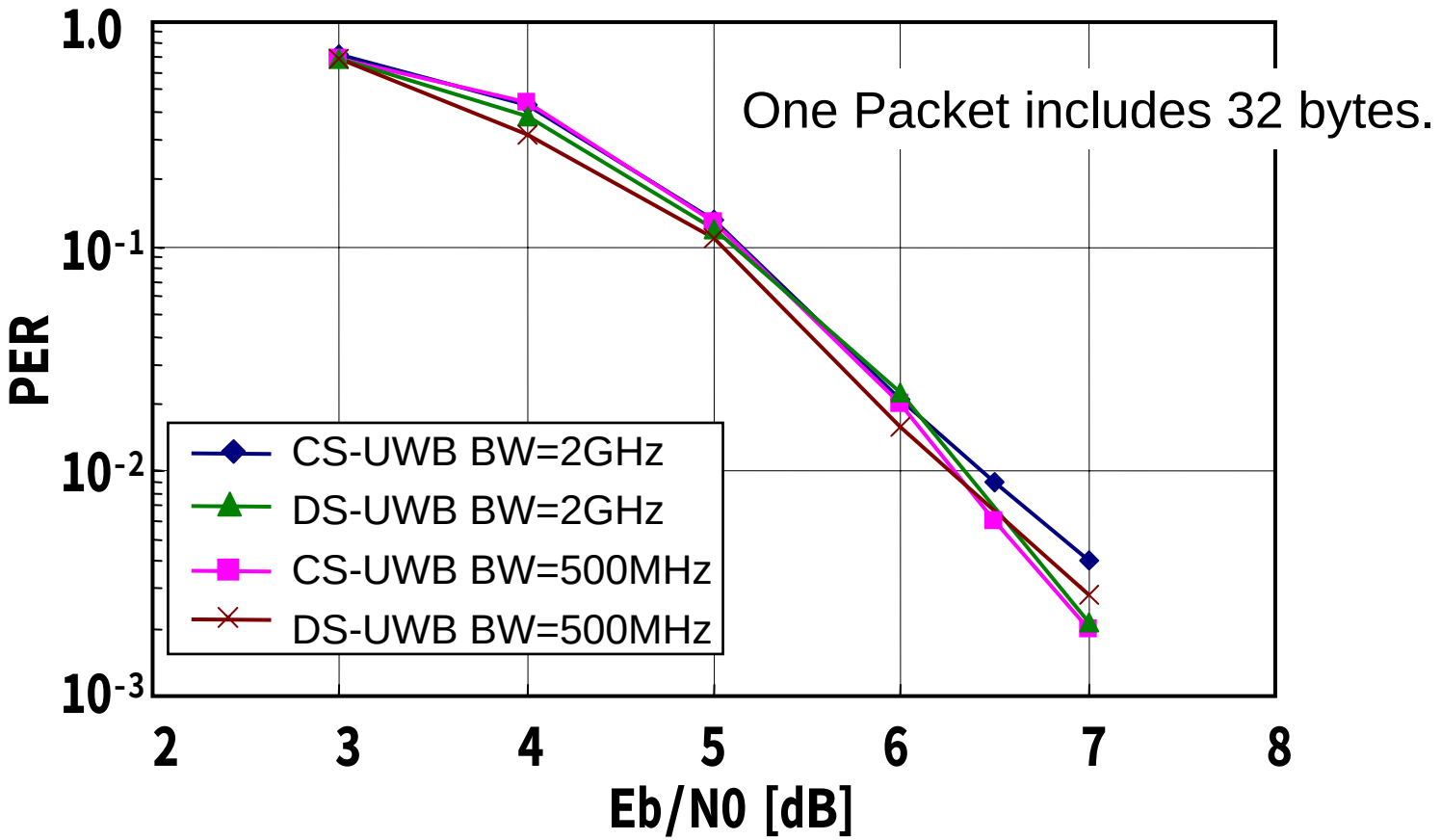
| Parameter | Value | Value | Unit |
|---|---|---|---|
| Distance (d) | 30 | 10 | m |
| Peak payload bit rate (Rb) | 1 | 1024 | kbps |
| Average Tx power (Pt) | -10.5 | | dBm |
| Tx antenna gain (Gt) | -3.00 | | dBi |
| Frequency band | 3.1 - 5.1 | | GHz |
| Geometric center frequency (fc) | 3.98 | | GHz |
| Path loss @ 1m (L1) | 44.43 | | dB |
| Path loss @ d m (Ld) | 29.54 | 20.00 | dB |
| Rx antenna gain (Gr) | -3.00 | | dBi |
| Rx power (Pr) | -90.47 | -80.93 | dBm |
| Average noise power per bit (N) | -144.00 | -113.90 | dBm |
| Rx Noise figure (Nf) | 7.00 | | dB |
| Average noise power per bit (Pn) | -137.00 | -106.90 | dBm |
| Minimum required Eb/N0 (S) | 6.25 | | dB |
| Implementation loss (I) | 3.50 | | dB |
| **Link Margin** | 36.78 | 16.22 | dB |
| **Min. Rx Sensitivity Level** | -127.25 | -97.15 | dBm |

# CS-UWB Link Budget (BW=500MHz)

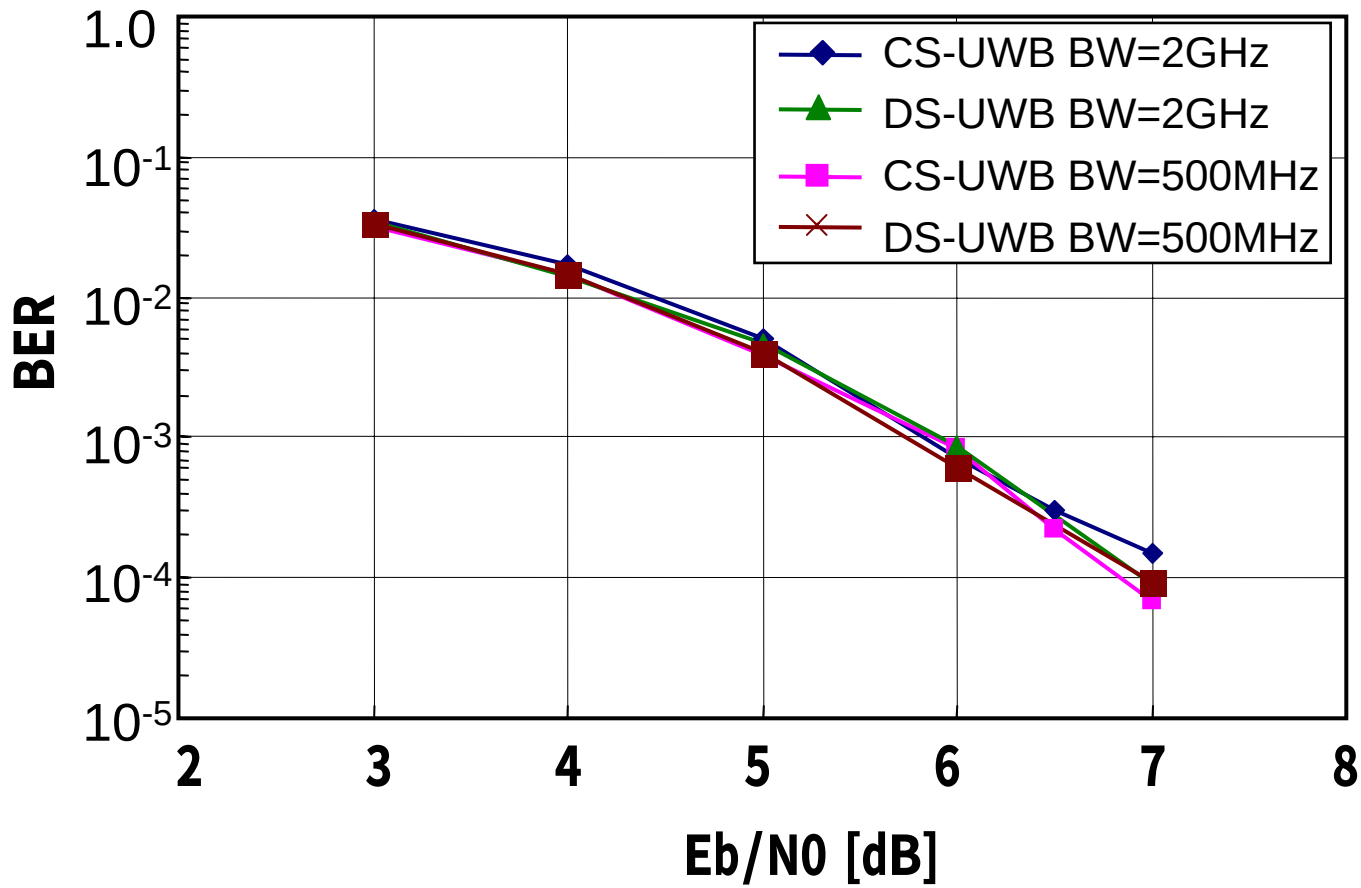
| Parameter | Value | Value | Notes |
|---|---|---|---|
| Data rate (Rb) | 1 | 1024 | (kbps) |
| Modulation | BPSK | | Coherent detection |
| Coding rate (R) | ½ | | (24,12)-Extended Golay Hard-decision decoding |
| Raw Symbol rate (Rs) | 2 | 2048 | Rs=Rb/R (ksymbol/s) |
| Chirp signal duration (Tc) | 25 | | (ns) |
| Spreading code length (Ns) | 1024 | 16 | |
| Chip rate (Rc) | 2.048 | 32.768 | =Rs*Ns (MHz) |
| Chip duration | 488.3 | 30.5 | =1/Rc (nsec) |

| Parameter | Value | Value | Unit |
|---|---|---|---|
| Distance (d) | 30 | 10 | m |
| Peak payload bit rate (Rb) | 1 | 1024 | kbps |
| Average Tx power (Pt) | -16.9 | | dBm |
| Tx antenna gain (Gt) | -3.00 | | dBi |
| Frequency band | 3.1 - 3.6 | | GHz |
| Geometric center frequency (fc) | 3.34 | | GHz |
| Path loss @ 1m (L1) | 42.92 | | dB |
| Path loss @ d m (Ld) | 29.54 | 20.00 | dB |
| Rx antenna gain (Gr) | -3.00 | | dBi |
| Rx power (Pr) | -95.36 | -85.82 | dBm |
| Average noise power per bit (N) | -144.00 | -113.90 | dBm |
| Rx Noise figure (Nf) | 7.00 | | dB |
| Average noise power per bit (Pn) | -137.00 | -106.90 | dBm |
| Minimum required Eb/N0 (S) | 6.25 | | dB |
| Implementation loss (I) | 3.50 | | dB |
| **Link Margin** | 31.89 | 11.33 | dB |
| **Min. Rx Sensitivity Level** | -127.25 | -97.15 | dBm |

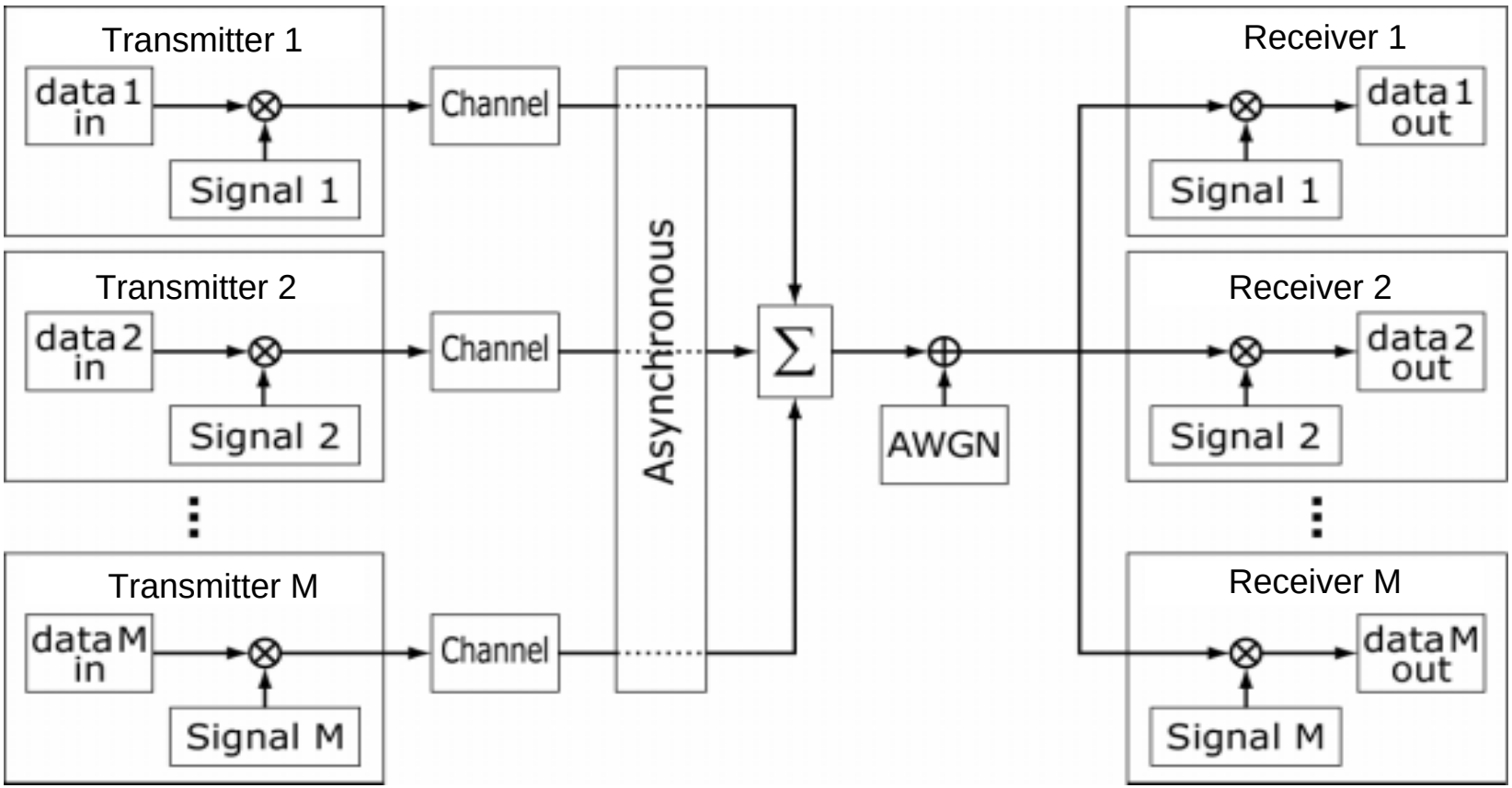
# Simulation results (Single link)



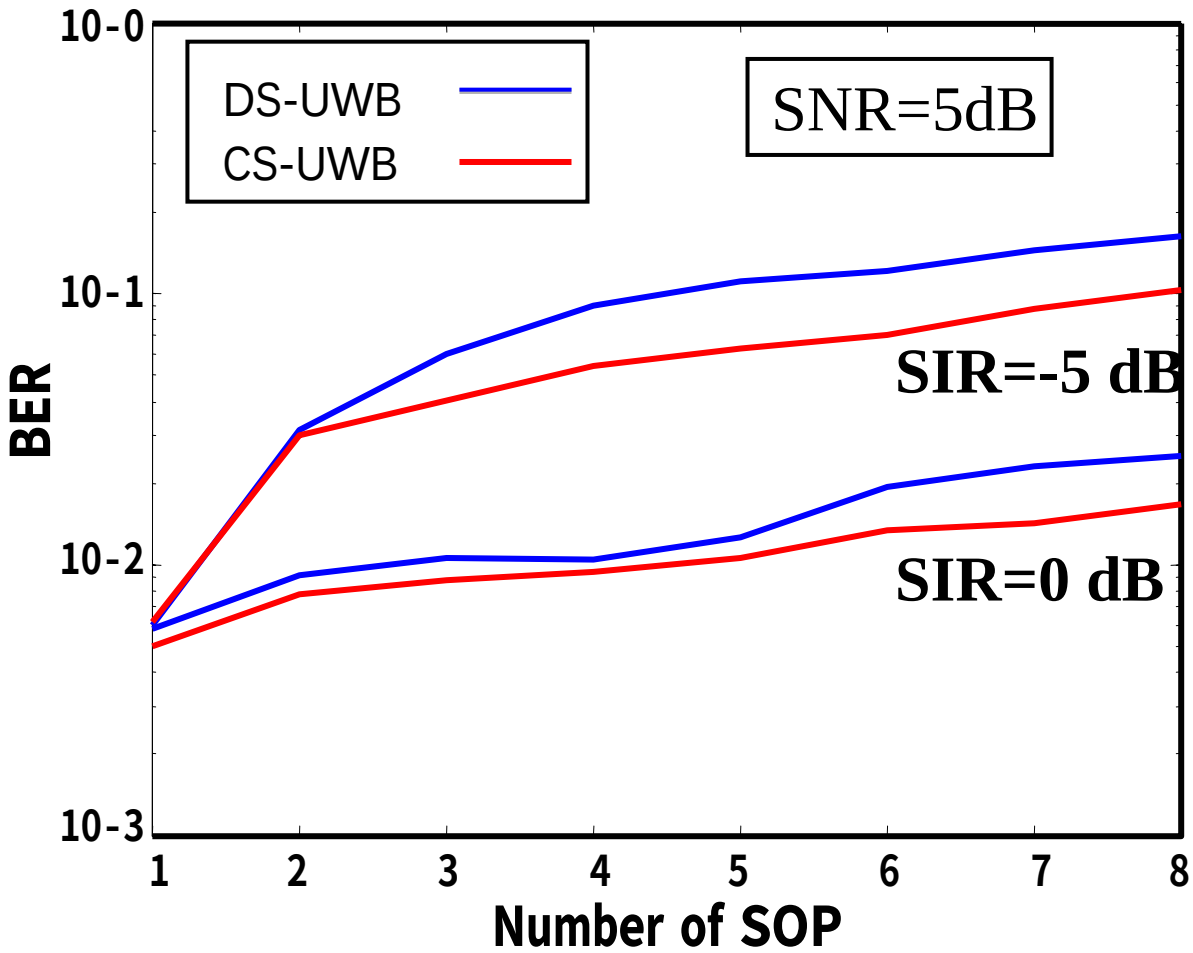
# Simulation results (Single link)



# Simulation block diagram for SOP



# Simulation results for SOP



# Ranging issue

- Ranging precision depends on the frequency bandwidth used.
- Using a simple TOA, DS-UWB provides better precision than CS-UWB in principle.

# DS-UWB and CS-UWB Summary

++ good, + fair

| | DS-UWB | CS-UWB |
|---|---|---|
| Low complexity | ++ | + |
| Peak-to-average ratio | + | ++ |
| Effect of SOP | + | ++ |
| Ranging precision | ++ | + |

# Conclusions

- DS-UWB and CS-UWB are good candidates for 15.4a.
  - Have similar characteristics and advantages.
  - Present similar performances but have own strength at different aspects.
  - Can be further improved
- Both can meet the Technical Requirements.
  - Low complexity, low cost, low power consumption.
  - Precision ranging.
  - Robustness.
- More studies are on going and will be presented at January meeting.