Satellite Communications using Ultra Wideband (UWB) Signals

March 3, 2004

Yoshio KUNISAWA  Hiroyasu ISHIKAWA
Hisato IWAI  Hideyuki SHINONAGA

KDDI R&D LABORATORIES
Background (1)

- UWB (Ultra WideBand) is expected to realize high speed data transmission for terrestrial short distance communications.

- The standardization activity of the UWB radio system was started in IEEE802.15.

- UWB devices have good features for terminals such as simple hardware configuration, low power consumption, etc.
Effective use of an electric wave is desired also in the satellite communication.

Assuming UWB signal can be overlaid on other system spectrum without vast interference.

Satellite communications using UWB signals have possibility to enable new services and new markets.

Initial results on link budget calculation and estimation of signal transmission speed is presented.
What's UWB? (Short pulse type)

- Short duration pulse has wide bandwidth.

- Data is encoded by pulse modulation such as PPM or PAM.
UWB regulation of FCC (1)

- Specifications for communication devices using UWB

  - BANDWIDTH:
    Fractional bandwidth equal to or greater than 0.2, or bandwidth equal to or greater than 500 MHz.

![Diagram showing bandwidth calculation](https://via.placeholder.com/150)

Relative power

-0 dB 0 dB

Frequency

Center frequency

Fractional bandwidth = bandwidth / center frequency
UWB regulation of FCC (2)

- **RADIATED EMISSIONS**:  
  0.96 - 1.61 GHz < -75.3 dBm/MHz 
  1.61 - 1.99 GHz < -63.3 dBm/MHz 
  1.99 - 3.1 GHz < -61.3 dBm/MHz 
  3.1 - 10.6 GHz < -41.3 dBm/MHz 
  10.6 GHz - < -61.3 dBm/MHz

- **PEAK LEVEL OF EMISSIONS**:  
  A peak level of the emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission is 0 dBm EIRP.
Concept of Satellite UWB

- Adopt UWB in Satellite Communications
- Using Ku-band FSS

Uplink Ku-band (14 GHz) Narrowband signal

Downlink Ku-band (12 GHz) UWB signal

Regenerative Satellite

Satellite UWB

UWB device

the Earth
Satellite UWB spectrum

Overlaying onto existing systems
Link budget

- Received power level is much smaller than signal level of terrestrial UWB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>12</td>
<td>GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>500</td>
<td>MHz</td>
</tr>
<tr>
<td>Transmission power</td>
<td>20.3</td>
<td>dBW</td>
</tr>
<tr>
<td>Satellite antenna diameter</td>
<td>1.27</td>
<td>m</td>
</tr>
<tr>
<td>Satellite antenna gain (efficiency = 60%)</td>
<td>41.8</td>
<td>dBi</td>
</tr>
<tr>
<td>EIRP</td>
<td>65.1</td>
<td>dBm/MHz</td>
</tr>
<tr>
<td>Link margin</td>
<td>5</td>
<td>dB</td>
</tr>
<tr>
<td>Rain margin</td>
<td>3</td>
<td>dB</td>
</tr>
<tr>
<td>Path loss to the earth surface (at 12 GHz)</td>
<td>205.2</td>
<td>dB</td>
</tr>
<tr>
<td>Power density at earth surface</td>
<td>-148.1</td>
<td>dBm/MHz</td>
</tr>
</tbody>
</table>

3m from the terrestrial UWB transmitter is -100.0 dBm/MHz
Throughput using PAM (1)

- Employ PAM (Pulse Amplitude Modulation)
- Symbol error probability of M-ary PAM

\[ P_M = \frac{M - 1}{M} \text{erfc} \left( \frac{3}{M^2 - 1} \times \frac{E_s}{N_0} \right) \]

\( E_s/N_0 \) : signal power per symbol to noise power density ratio

- Bit error probability

\[ P_b = \frac{1}{k} P_M \]

\( k \) : the number of bits transmitted in a symbol
Throughput using PAM (2)

- Required $E_s/N_0$ for BER = $10^{-3}$

<table>
<thead>
<tr>
<th>$M$</th>
<th>Required $E_s/N_0$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>13.75</td>
</tr>
<tr>
<td>8</td>
<td>19.77</td>
</tr>
<tr>
<td>16</td>
<td>25.5</td>
</tr>
</tbody>
</table>
Throughput using PAM (3)

- $E_s/N_0$ presented by pulse repetition frequency

$$E_s/N_0 = P_{ave}T_p/N_0 = [P_{sd}/N_0] \times [B_s/B_p]$$

- $P_{ave}$: Average received power
- $T_p$: Pulse repetition period
- $P_{sd}$: Average power spectral density
- $B_s$: Equivalent occupied bandwidth
- $B_p$: Pulse repetition frequency

$$B_p = [P_{sd}/N_0] \times B_s/N_F /[E_s/N_0]$$
Throughput using PAM (4)

- Achievable throughput
  - Assuming free-space propagation

\[ P_{sd} = -208.1 \text{ [dBm/Hz]} \]
\[ B_s = 500 \text{ [MHz]} \]
\[ N_0 = -174 \text{ [dBm/Hz]} \text{ (at room temperature)} \]
\[ N_F = 6 \text{ [dB]} \]

<table>
<thead>
<tr>
<th>Configuration</th>
<th>2-ary</th>
<th>4-ary</th>
<th>8-ary</th>
<th>16-ary</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 [dBi] (Same as terrestrial UWB)</td>
<td>9.96 k</td>
<td>4.21 k</td>
<td>1.58 k</td>
<td>563</td>
</tr>
<tr>
<td>5.0 [dBi] (Patch antenna)</td>
<td>31.5 k</td>
<td>13.3 k</td>
<td>4.99 k</td>
<td>1.78 k</td>
</tr>
<tr>
<td>19.8 [dBi] (10 cm dish)</td>
<td>951 k</td>
<td>402 k</td>
<td>151 k</td>
<td>53.7 k</td>
</tr>
<tr>
<td>33.7 [dBi] (50 cm dish)</td>
<td>23.3 M</td>
<td>9.87 M</td>
<td>3.70 M</td>
<td>1.32 M</td>
</tr>
<tr>
<td>39.8 [dBi] (1 m dish)</td>
<td>95.1 M</td>
<td>40.2 M</td>
<td>15.1 M</td>
<td>5.37 M</td>
</tr>
</tbody>
</table>
Multiband-UWB signal

- Symbol structure example of MB-UWB
Throughput using MB-UWB (1)

Subpulse error probability of MB-UWB

\[ P_s = 4(S - 1)Q \left( \frac{2E_{sp}}{N_0} \right) \]

\( S \): Number of frequency bands
\( E_{sp} \): Energy per subpulse
\( N_0 \): Noise spectral density

\[ E_s = E_{sp} \times S \]

Required \( E_s/N_0 \) for subpulse error rate of \( 10^{-3} \)

<table>
<thead>
<tr>
<th>( S )</th>
<th>Required ( E_s/N_0 ) [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>14.5</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
</tr>
</tbody>
</table>
Throughput using MB-UWB (2)

- **Pulse repetition frequency**

  \[ B_p = \left[ \frac{P_{sd}}{N_0} \right] \times B_s \times N_F \times \left[ \frac{E_s}{N_0} \right] \]

- **Achievable throughput**

  \[ R = B_p \times \left[ \log_2 (S!) + SP \right] \]

  \[ S: \text{Number of frequency bands} \]

  \[ P: \text{Number of polarity bits} \]

<table>
<thead>
<tr>
<th></th>
<th>4-bands</th>
<th>8-bands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BPSK</td>
<td>QPSK</td>
</tr>
<tr>
<td>0 [dBi] (Same as terrestrial UWB)</td>
<td>15.2 k</td>
<td>22.3 k</td>
</tr>
<tr>
<td>5.0 [dBi] (Patch antenna)</td>
<td>48.1 k</td>
<td>70.5 k</td>
</tr>
<tr>
<td>19.8 [dBi] (10 cm dish)</td>
<td>1.45 M</td>
<td>2.13 M</td>
</tr>
<tr>
<td>33.7 [dBi] (50 cm dish)</td>
<td>35.6 M</td>
<td>52.3 M</td>
</tr>
<tr>
<td>39.8 [dBi] (1 m dish)</td>
<td>145 M</td>
<td>213 M</td>
</tr>
</tbody>
</table>
Conclusion

- Possibility of satellite UWB is considered.
- Received signal power density at the earth's surface is much smaller than the signal level of the terrestrial UWB.
- High throughput can be realized by satellite UWB under our assumptions.
- The satellite UWB has possibility to enable new services, and is expected to open new markets.
Thank you!