NextNav Metropolitan Beacon System (MBS) ICD

Version G1.0

April 24, 2014

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Abstract

This document describes the air interface of the Metropolitan Beacon System (MBS) system. MBS provides a high precision, reliable, consistent positioning system indoors and in urban canyons, where GNSS solutions are degraded or denied. In addition to the high 2-D accuracy, the MBS system architecture also provides for high resolution and accuracy in the vertical dimension, with the aid of embedded sensors. MBS technology provides a very fast time to first fix (TTFF), on the order of ~6 seconds under cold start conditions. Similar to GNSS, MBS

technology allows computation of the location on the device without any network dependence thus enabling a wide variety of standalone applications.

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1 Introduction

This document describes the air interface of the Metropolitan Beacon System (MBS) system.

2 MBS System Features

MBS provides a high precision, reliable, consistent positioning system indoors and in urban canyons, where GNSS solutions are degraded or denied.

In addition to the high 2-D accuracy, the MBS system architecture also provides for high resolution and accuracy in the vertical dimension, with the aid of embedded sensors.

MBS technology provides a very fast time to first fix (TTFF), on the order of ~6 seconds under cold start conditions.

Similar to GNSS, MBS technology allows computation of the location on the device without any network dependence thus enabling a wide variety of standalone applications.

3 High Level Architecture

The high level system architecture is shown in Figure 1.

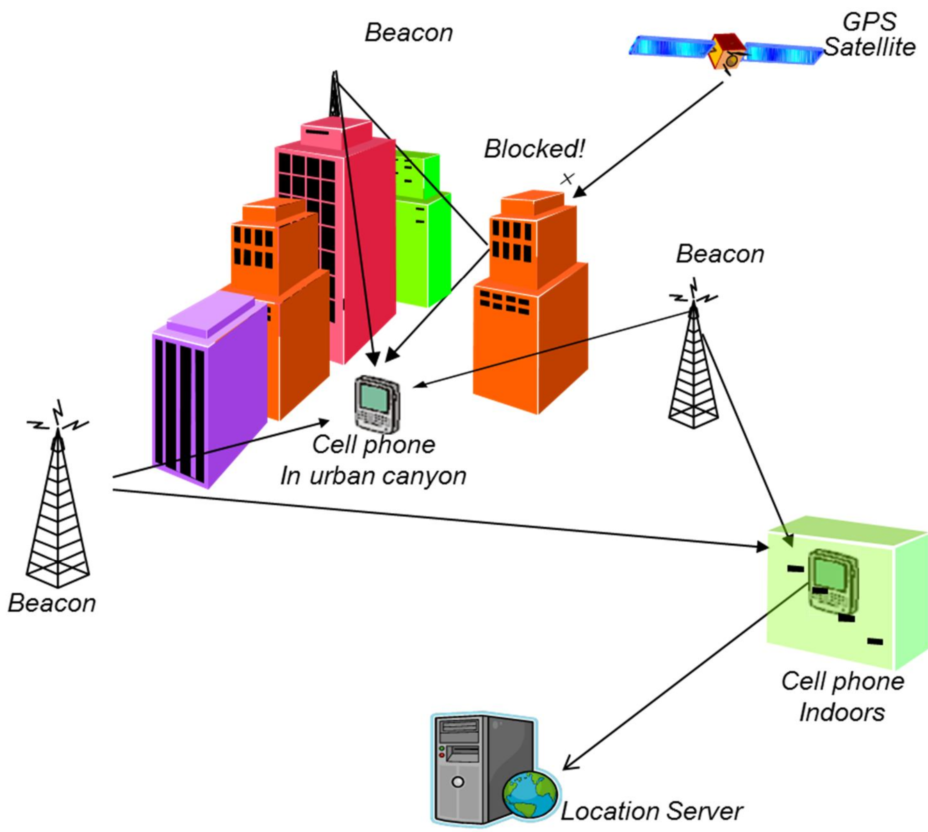

Figure 1: MBS System Architecture

MBS beacons are an overlay network used to cover a metropolitan area. One implementation uses licensed wireless spectrum in the M-LMS band. Various components in Figure 1 are described below:

Beacon: The beacons in this figure denote the MBS beacons broadcasting the MBS signal. The beacons may be housed on roof tops or towers (typically pre-existing cell/broadcast sites), or in any other location deemed appropriate by the operator of the MBS network.

Cell Phone: An example device that needs location information is shown as a cell phone under GNSS-challenged conditions such as urban canyons and indoors where GNSS signals from satellites may not be received reliably or may provide poor performance. The cell phones shown in the figure would be capable of receiving and processing MBS signals. Note that any device equipped to process MBS signals would work under these scenarios. A data or a voice connection is NOT required for a device to compute its location using the MBS technology.

Location Server: In certain applications, it may be useful for a centralized server to compute the location with information it receives from the mobile because of the additional information that may be available to the server device at the time of location determination.

GPS Satellite: Shown for illustrative purposes that it is blocked by buildings in an urban canyon.

4 MBS M1 Signal Structure

4.1 MBS M1 Signal Generation

The MBS signal shall be generated from a PN sequence and BPSK spreading. The chipping rate shall be 1.023 $m/2$ Mchips/sec, where *m* is an integer greater than or equal to 2, and the length of the PN sequence shall be 1024 $n - 1$, where *n* is an integer greater than or equal to 1.

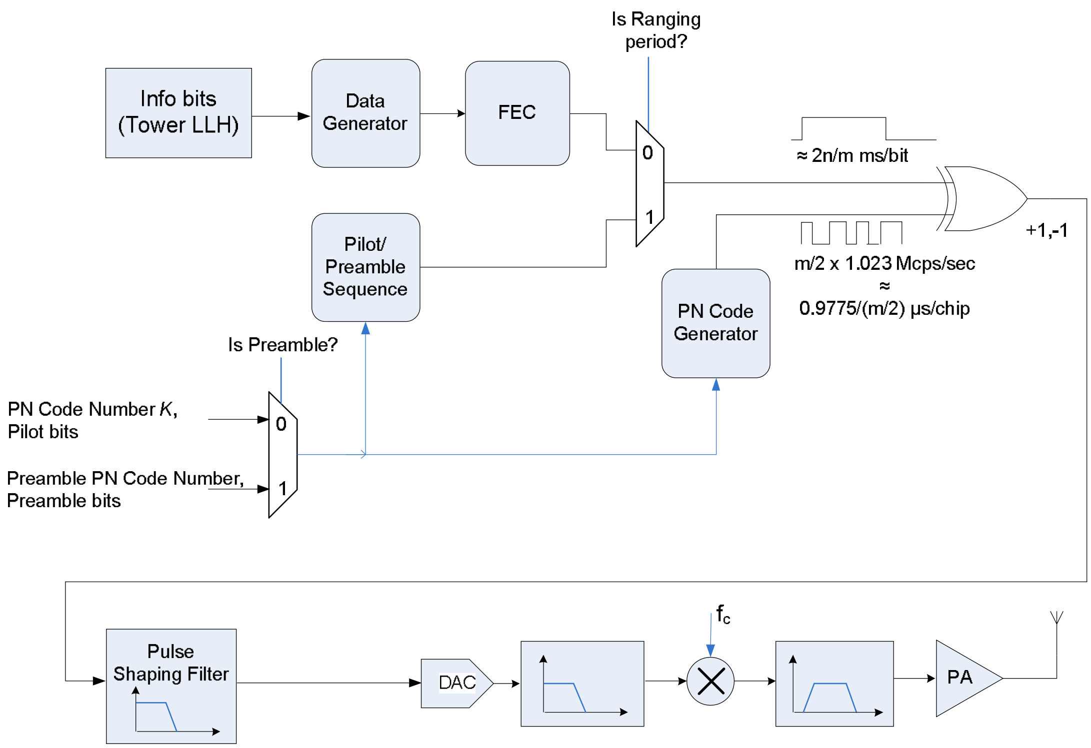

Figure 2: MBS M1 Signal Generation

The various blocks in the Signal Generator are described below:

1 **PN Code Generator:** Generates binary waveforms of length 1024 $n - 1$. The PN code generator generates chips at the rate of 1.023 $m/2$ Mchips/sec (period of each chip is 1/1.023/(m/2) µs).

2 **Data Generator:** Collects information from sensors and other information such as tower Latitude, Longitude, Height (LLH) and other information and formats them into frames and sub-frames.

3 **FEC:** Adds forward error correction. See Figure 7 for detailed block diagram.

4 **Pilot/Preamble Sequence:** During some periods (preamble and ranging periods) MBS beacons transmit a known sequence of bits. During the preamble, they transmit the preamble bits, which help with acquisition. During ranging periods, they transmit pilot bits, which enable long coherent integration to improve ranging performance.

A timing view of the data that is being sent at the output of the XOR gate in Figure 3 is shown below:

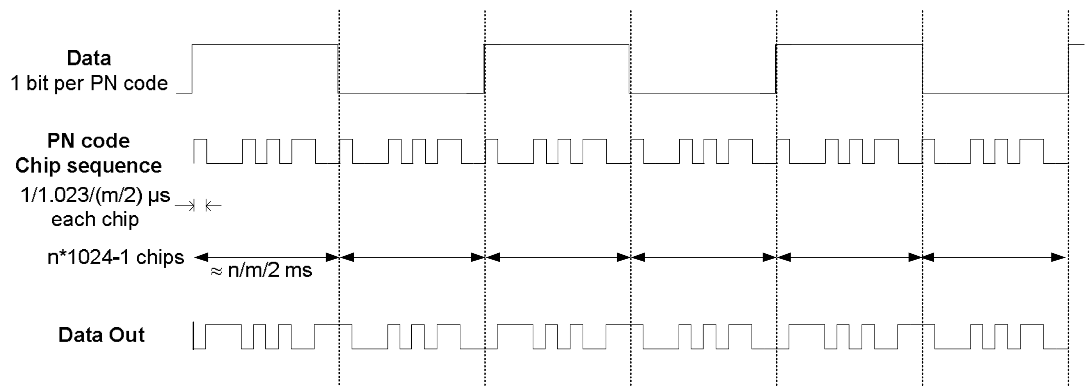

Figure 3: Timing View of XOR'd data

4.2 Spectral Characteristics

The transmit spectrum shall have the following characteristics:

Parameter	Value
Tx transmission type	Spread spectrum transmission using BPSK spreading
RF BW (null-to-null)	1.023 m MHz, where m = 2,3,4,...

The Tx center frequency may be in any band. In the USA, one frequency allocation for MBS is in the LMS band, in the range 920.773 MHz to 926.277 MHz.

The transmit filter taps for the USA LMS band are in Appendix A, and the frequency response of the transmit filter is shown in Figure 4, for sample values of m and n, where m=2, n=1.

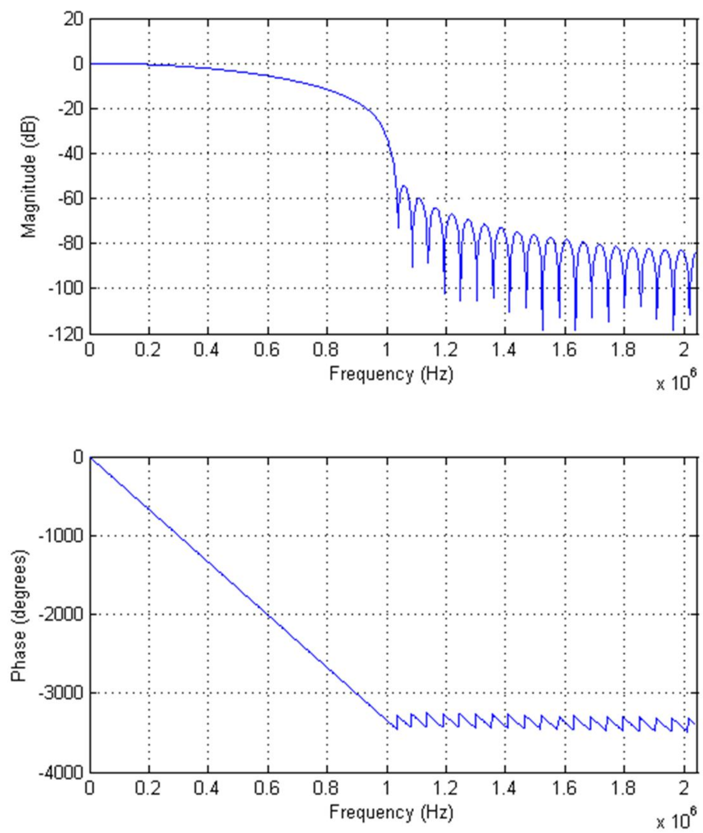

Figure 4: Frequency response of the transmit filter when m=2, n=1

4.3 MBS Signal Temporal Characteristics

The MBS architecture shall use an access scheme where each beacon transmits its data for a specified duration within each transmission period.

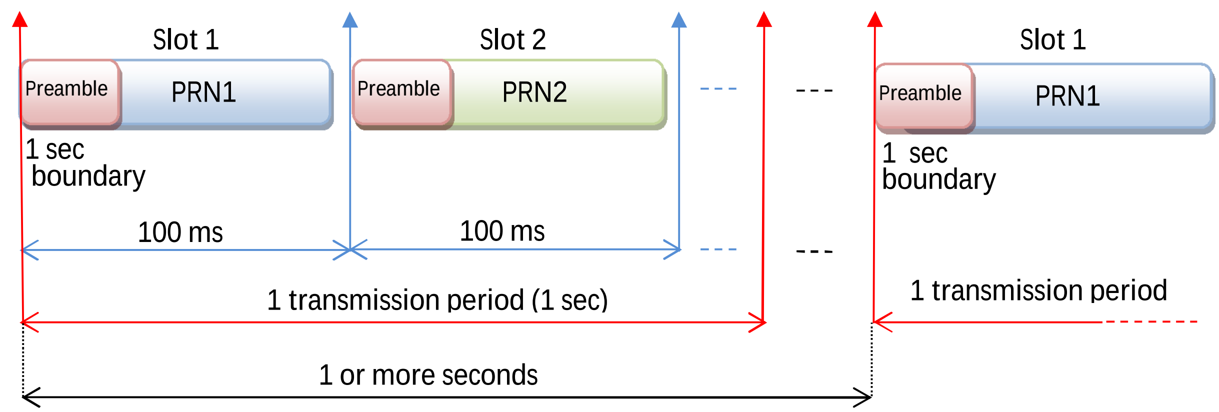

Figure 5: Sample Slotted MBS Mode

System parameters:

- Each transmission period shall be 1sec long
  - Transmission periods shall be Δ_T seconds apart, where Δ_T shall be an integer greater than or equal to 1
- There shall be ten 100ms slots in each transmission period
- The MBS signal shall be generated from a PRN sequence and BPSK spreading
- Each transmitter shall be assigned
  - One of the ten slots as its primary slot
  - One PRN code
- Additional optional transmitter parameters include
  - A primary slot pattern
    - This is a sequence of slot indexes (each one in the range 1 to 10), that determine which slot the transmitter will transmit in successive seconds of transmission.
    - The sequence may be as basic as a simple repetition of the primary slot, or may be any sequence of slot indexes, with each transmitter potentially having a different periodicity in their slot pattern.
  - Secondary slot patterns
    - Each beacon may have up to nine secondary slot patterns.
    - These may have the same or different PRN as the primary slot pattern of that transmitter, and will have a transmit power that should be between 0dB to 50dB lower than the transmit power of the primary slot pattern.

  - Frequency offset
- The chipping rate shall be 1.023 $m/2$ Mcps, where *m* is an integer greater than or equal to 2.
- Each PN code shall have 1024 $n-1$ chips and lasts $\frac{n+(n-1)/1023}{m/2}$ ms
  - Every 100ms slot includes $\frac{100\ m/2}{n+(n-1)/1023}$ PN code symbols
  - One PN code symbol must be used as a guard time between slots, therefore there are $\frac{100\ m/2}{n+(n-1)/1023}-1$ PN code symbols available for ranging and data transmission in each 100ms.
  - For example, when m=2 and n=1, the system can fit 100 PN code symbols in 100ms, out of which 99 are available for ranging and data transmission.
- Each beacon transmits a preamble using a PN code reserved only for preambles.
  - Ranging slots (described in the next section) have a preamble of length p_R PN codes (leaving $\frac{100\ m/2}{n+(n-1)/1023}-1-p_R$ PN codes for pilot symbols)
  - Hybrid slots (described in the next section) have a preamble of length p_H PN codes (leaving $\frac{100\ m/2}{n+(n-1)/1023}-1-p_H$ PN codes for pilot and data symbols)
- A list of possible PN Codes used by MBS is shown in Appendix B.

5 Databurst Format

MBS uses the concept of databursts in order to be able to transmit all the data required for trilateration (such as latitude, longitude, etc.) in a short amount of time, and also be able to perform long coherent integrations to enable high ranging accuracy. An optional implementation would be to divide the time available to a transmitter into ranging portions and data portions. During the ranging part, transmitters transmit pilot symbols that enable long coherent integration, and during the data part, transmitters transmit data symbols at a physical-layer rate of 1 bit per PN code period. An optional slot structure, implementing the above methodology, is presented below.

5.1 Slot Structure

1. Separate slots for ranging and data
    - One slot uses BPSK pilot symbols for ranging
    - This may be followed by one or more slots that are hybrid (ranging & data slots)
2. Use error-correcting codes & CRC for the data portions

In general, an MBS deployment may have zero or more hybrid slots for each ranging slot. In scenarios where there are zero hybrid slots, receivers must obtain assistance data via another channel in order to perform trilateration.

One possible implementation, for the sample scenario of m=2,n=1, which results in 99 PN code symbols per 100ms being available for ranging and data transmission, uses the following settings:

- Slot structure consists of one ranging slot followed by two hybrid slots
    - This structure is referred to as RH1H2 and is depicted in the Figure below
- Ranging slots:
    - 7 PN codes for preamble
    - 92 PN codes for pilot symbols
- Hybrid ranging & data slots:
    - 4 PN codes for preamble
    - 14 PN codes for pilot symbols
    - 81 PN codes for data transmission using BPSK at 1 PN code/symbol

Figure 6: Optional slot structure for a given transmitter. The blocks above are 1 or more sec apart and represent 1 slot (100ms). The lengths of the preamble, pilot, and data portions in the above diagram correspond to the sample scenario where m=2,n=1 and where there are two hybrid slots for each ranging slot.

Using the RH1H2 slot structure and sample implementation from above, MBS is able to support 102 information bits in one data packet. These information bits are used for transmitting information required for trilateration (such as Tx lat/long/altitude).

In terms of alignment of above slot structure to GPS time, MBS physical slot 1 of the R frame (see Figure 5) starts at 'GPS time in seconds' modulo 3 = 0, plus 'GPS time offset' (from MBS packet type 2, described in Section 6.3.1.5)

5.2 Error-correcting code and CRC check

MBS shall use error-correcting codes to ensure operation at low SNRs and uses CRC to ensure that the decoded bits are valid. The error-correcting codes and CRC polynomials chosen for MBS may vary from implementation to implementation.

The remainder of this section describes the implementation with the RH1H2 slot structure and the sample scenario of m=2,n=1, which uses a convolutional code with constraint length 7 and a 16-bit CRC polynomial.

A block diagram of the encoding process is shown in Figure 7.

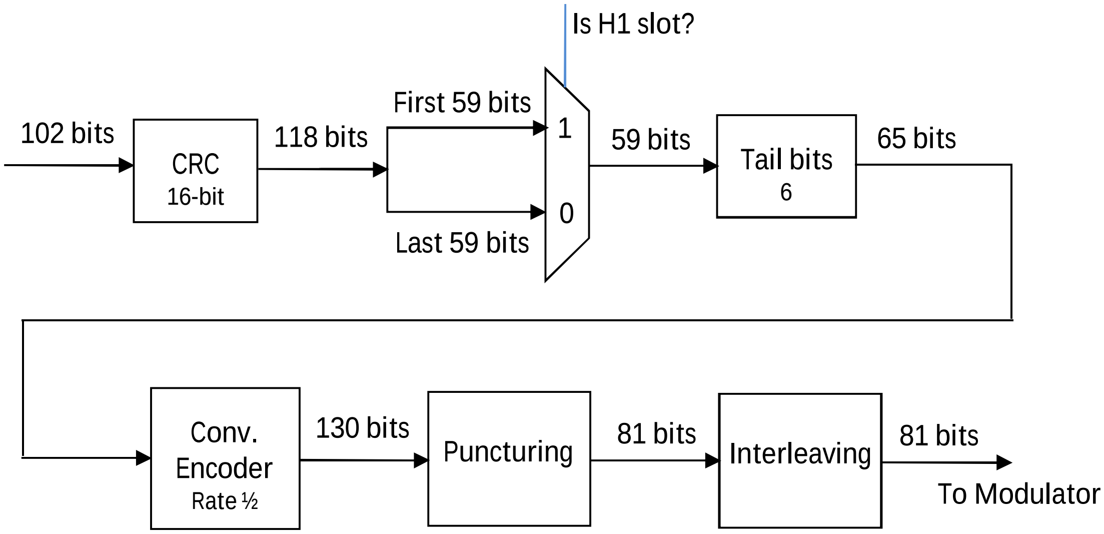

Figure 7: Encoding process, for RH1H2 slot structure and sample scenario of m=2,n=1

The CRC check is accomplished using a length-N_{crc} CRC code. The value of N_{crc} is 16, and the CRC polynomial used is x^16 + x^15 + x^12 + x^7 + x^6 + x^4 + x^3 + 1.

Each of the two hybrid slots is encoded and decoded separately, though the CRC is common to both slots. That is, the transmitter takes the 102 information bits, calculates the 16 bits of CRC, resulting in 118 bits. It then divides these 118 bits into two parts of length 59 bits, and it is these 59 bits which are encoded and transmitted using the 81 available PN code symbols in each hybrid slot.

The error-correcting code used is a convolutional code. The code has constraint-length 7 and is a rate-1/2 code that is punctured to ensure that the encoded bits fit within the 81 available PN code symbols in each hybrid slot. The transmitter adds 6 all-zero tail bits to the information bits before encoding, due to the nature of convolutional coding and decoding.

The encoding process shown in Figure 7 and described above can also be visualized in Figure 8

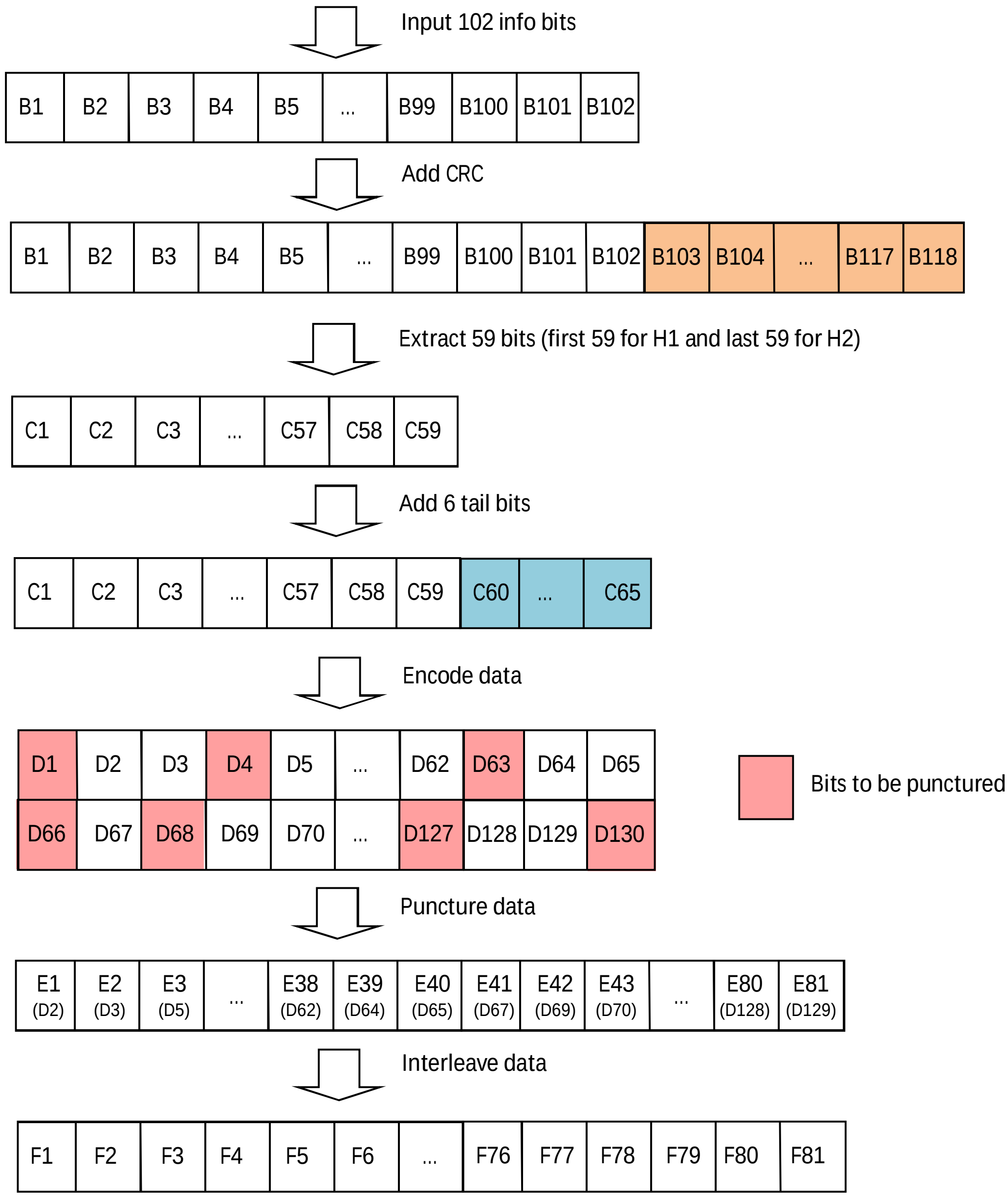

Figure 8: Encoding process visualization

The encoding process for this sample scenario can be summarized as:

1. Take 102 info bits as inputs
2. Add 16 CRC bits, to end up with 118 bits
3. Split into two groups of 59 bits (first 59 for H1 slot last 59 for H2)
4. For each group of 59 bits

a. Add 6 tail bits, to end up with 65 bits
b. Encode using the rate ½ encoder, to end up with 130 bits
c. Puncture the output of the encoder, to end up with 81 bits
d. Interleave the above bits, and send the result to the modulator, to be transmitted over-the-air to the receiver.

Encoder information

- Convolutional encoder of rate: ½
- Constraint-length: 7
- Encoder polynomials: [171 133] (in octal)
- Puncturing pattern: Of the 130 encoder output bits, select 81, according to
  $b_{punct}[k] = b_{enc}[idx\_pass[k]]$, k = 0 to 80
  where

```
idx_pass[] = {
1,2,4,6,7,9,10,12,14,15,17,18,20,21,23,25,26,28,29,31,33,34,36,37,3
9,41,42,44,45,47,49,50,52,53,55,57,58,60,61,63,64,66,68,69,71,72,74
,76,77,79,80,82,84,85,87,88,90,92,93,95,96,98,100,101,103,104,106,1
07,109,111,112,114,115,117,119,120,122,123,125,127,128 };
```

- Interleaving pattern: From the input bit sequence $b_{punct}[k]$ where k = 0 to 80, calculate the output bit sequence $b_{out}[k]$ according to
  $b_{out}[k] = b_{punct}[idx\_permute[k]]$, k = 0 to 80
  where idx_permute is the following length-81 array:

```
idx_permute[] = {
4,21,80,65,39,35,6,32,8,47,45,25,23,76,41,16,30,7,46,11,9,51,2,43,7
1,79,69,74,50,70,78,10,62,17,60,15,13,5,68,36,27,72,75,40,38,54,24,
52,64,58,55,20,63,59,26,67,31,49,0,56,42,61,53,66,3,18,48,22,34,57,
12,33,19,37,73,28,1,29,77,44,14 };
```

(The receiver demodulates the signal in each slot, de-interleaves the resulting soft bits and passes them through the decoder. The receiver concatenates the output of the decoder from the two hybrid slots H1 and H2 and does a CRC check to ensure that the block of data was sent successfully)

5.3 Modulation

In ranging slots, after the preamble, MBS shall use BPSK modulation to transmit $\frac{100\ m/2}{n+(n-1)/1023} - 1 - p_R$ pilot bits over the same number of PN code periods. These are the pilot bits that enable the long coherent integration times. The pilot bit sequence during ranging slots is described below.

In hybrid slots, after the preamble, there are $\frac{100\ m/2}{n+(n-1)/1023} - 1 - p_H$ PN code periods left in the slot. MBS uses BPSK modulation to transmit pilot bits over a subset of these code periods, and then uses DBPSK (differential BPSK) modulation to transmit data bits over the remaining PN code periods. The transmitter uses the last pilot bit as the first DBPSK data bit so that it can maximize the number of data bits it can transmit, even though it is using DBPSK. The pilot bit sequence is different for H1 and H2 slots.

The pilot bit sequences for ranging and hybrid slots depend on the MBS network configuration and may be in one of two modes. The following are the two modes for the RH1H2 slot structure for the sample scenario of m=2,n=1 :

- Pilot Sequence Mode 1:
  - Ranging (R) slot:
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
  - H1 pilot sequence: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
  - H2 pilot sequence: 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1

- Pilot Sequence Mode 2:
  - R slot:
    1,1,1,1,1,0,1,0,1,1,0,1,0,0,0,1,1,0,1,1,0,0,1,1,1,0,0,0,0,1,0,
    1,1,0,1,1,0,1,0,1,1,1,0,0,1,0,0,1,1,1,0,0,1,1,0,0,0,1,1,0,1,1,
    0,0,1,0,1,1,0,0,0,1,0,0,1,1,0,1,0,0,0,0,0,1,0,1,1,1,1,1,0,1
  - H1 pilot sequence: 0, 1, 0, 0, 1, 1, 1, 0, 1, 0, 1, 1, 1, 0
  - H2 pilot sequence: 0, 0, 1, 0, 0, 1, 0, 1, 1, 1, 0, 0, 1, 0

In all sequences above, a ‘0’ is mapped to ‘-1’, and a ‘1’ is mapped to ‘1’ during modulation.

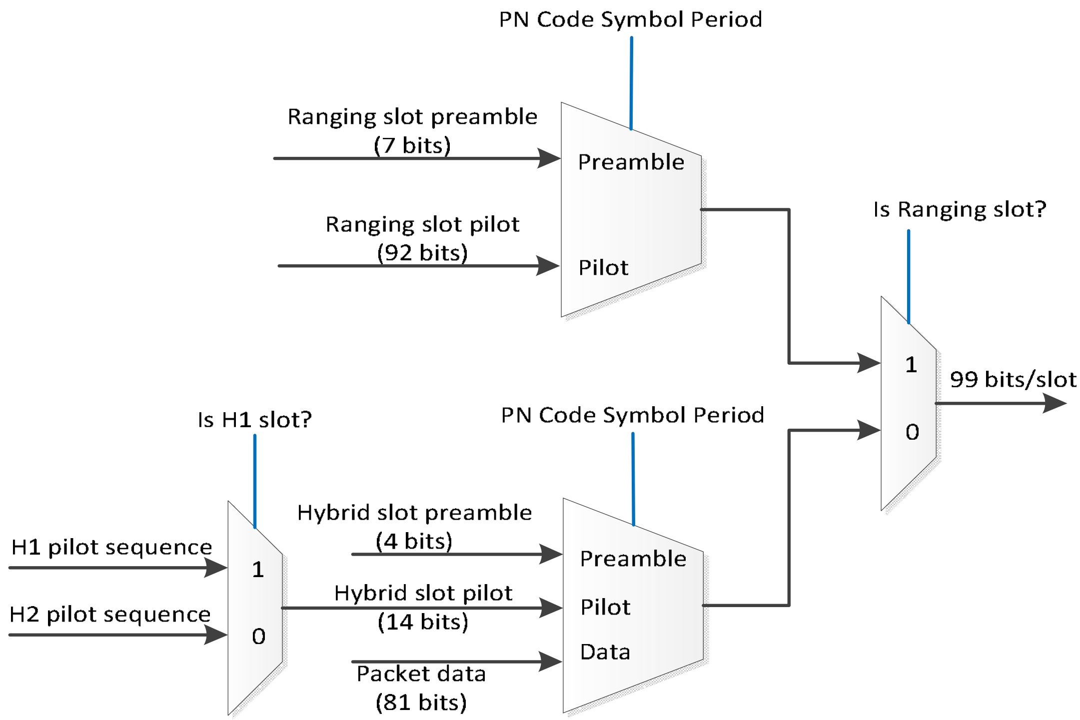

Figure 9: Modulation process for RH1H2 slot structure and sample scenario of m=2,n=1

6 Packet Types – MAC Layer

MBS supports various packet types, such as one that carries trilateration information and one that carries GPS time information. For each packet type, MBS could support encryption of the payload, and MBS service providers may choose to encrypt or may choose not to encrypt the various packets.

The remainder of this section describes the implementation corresponding to the RH1H2 slot structure and the sample scenario of m=2,n=1, which is able to carry 102 information bits per data packet.

The various packet types supported are listed in Table 1.

Table 1: Packet types

Type	Payload	Number of payload bits	Number of slots
0	Reserved	TBD	TBD
1	Lat, long, alt, pressure, temperature, weath_data_quality, tx_correction, tx_quality, reserved	99	2
2	TxID, pressure, temperature, weat_data_quality, tx_correction, GPS_time, GPS_time_offset, slot_idx, UTC_Time_Offset, reserved	96	2
3-6	Packet types reserved for future use	TBD	any
7	Reserved for future use to extend packet types	TBD	any

This section specifies how many bits are required to be transmitted for each field of each packet type listed above.

6.1 Overall Packet Structure

Since there is more than one data packet type, there is a need for an indicator to denote which one the Rx is seeing at any given time.

Three bits are allocated to describe the packet type. In future versions of MBS, extension packet types may be supported by using ‘111’ as the base packet type (to denote ‘more packet type information to come’), and then have a few bits after that to denote more packet types.

The total payload of the RH1H2 scheme is 102 information bits per RH1H2 triplet of slots. Out of those 102 bits, 3 are for packet type index, leaving 99 bits for the data payload and any other framing overhead.

If some data to be transmitted is more than can be carried in one RH1H2 packet, the Tx sends the data over more than one packet. In that case, there is a need for a scheme to identify how the bits from the current data packet fit into the overall set of data bits that are to be transmitted. In order to have unambiguous understanding by the receiver on what is being transmitted in each data packet the following scheme is used:

| X | X | X | Payload (99 bits) |

Figure 10: Packet structure for packet types 0 and 1

| X | X | X | Y | Z | W | Payload (96 bits) |

XXX : Packet type
Y : Reserved bit
Z : Start bit
W : Stop bit

Figure 11: Packet structure for packet types other than 0 and 1

0 | 1 | 1 | 0 | 1 | 0 | Payload (96 bits)	First frame of packet type 3
0 | 1 | 1 | 0 | 0 | 0 | Payload (96 bits)	Continuation of packet
0 | 1 | 1 | 0 | 0 | 0 | Payload (96 bits)	Continuation of packet
...	...
0 | 1 | 1 | 0 | 0 | 1 | Payload (96 bits)	Last frame of packet
1 | 1 | 0 | 0 | 1 | 0 | Payload (96 bits)	First frame of packet type 6
1 | 1 | 0 | 0 | 0 | 1 | Payload (96 bits)	Last frame of packet
1 | 0 | 0 | 0 | 1 | 1 | Payload (96 bits)	First & last frame of packet type 4

Figure 12: Packet structure examples

- In every packet of 102 bits, the first three bits are the packet type
- For packet types 0 and 1:
  - The next 99 bits contain the main packet payload
- For packet types other than 0 and 1:
  - The fourth bit is a reserved bit.
  - The fifth bit is the start bit, and denotes whether this frame begins a new packet (1) or the continuation of a previous packet (0).

- The sixth bit is the stop bit, and denotes whether this is the last frame of a packet (1) or a continuation frame of a packet (0).
- The next 96 bits contain the packet payload

Summary: 3 bits of framing overhead for packet types 0 and 1, and 6 bits of framing overhead for packet types other than 0 and 1.

6.2 Packet Structure for Packet Type 1 (Full Trilateration Information)

Table 2: Packet Info for Packet Type 1

Field	bit_index	num_bits
Packet type	1 – 3	3
Payload	4 – 102	99

Table 3: Payload for Packet Type 1

Field	field_id	bit_index	num_txbits
Latitude	1	1 – 26	26
Longitude	2	27 – 53	27
Altitude	3	54 – 68	15
Tx correction	4	69 – 73	5
Tx quality	5	74 – 77	4
Pressure	6	78 – 87	10
Temperature	7	88 – 94	7
Weather info (optional)	8	95 – 99	5

6.2.1 Descriptions of the fields of packet type 1

Individual MBS service providers should map the raw values of the bits for each field to a range and resolution they feel best meets their requirements. Below are descriptions and sample ranges for each field.

6.2.1.1 Latitude

Latitude of the Tx antenna. Sample range: [-90, 90] degrees.

6.2.1.2 Longitude

Longitude of the Tx antenna. Sample range: [-180, 180] degrees.

6.2.1.3 Altitude

Altitude of the Tx antenna. Sample range: [-500, 9000] meters.

6.2.1.4 Tx Correction

Tx correction is the residual timing error left over after the Tx adjusts its transmission to account for the various delays in the system, such as cable delays. The receiver needs to take the Tx correction into account to fine-tune the pseudorange estimate from each transmitter (the Tx correction value for a given beacon needs to be subtracted from the receiver time stamp of the time-of-arrival estimate for that beacon).

Sample range: [0,31] ns.

Note: A bit sequence of all ones for the Tx Correction bit field denotes an invalid Tx Correction value, i.e. the transmitter has not been able to determine the Tx Correction value.

6.2.1.5 Tx Quality

Each beacon transmits some bits that denote to the receiver some relative quality metric about that particular beacon.

Sample range: [0, 15].

6.2.1.6 Pressure

The transmitter shall transmit pressure information to the receiver.

One option is to transmit the pressure measured at the beacon. Another option may be to transmit a transformation of the pressure measured at the beacon. As a sample transformation, the transmitter may convert the pressure measured at the beacon to an estimated pressure at a reference altitude level.

Sample range: [94500, 106776] Pa.

6.2.1.7 Temperature

The temperature measured at the beacon, which represents ambient atmospheric temperature.

Sample range: [228, 330] Kelvin.

6.2.1.8 Weather Info (Optional)

Each transmitter may transmit some bits that denote to the receiver some extra information about the weather and/or weather equipment, to enable improved altitude calculation.

Some examples of such information are:

- Wind speed
- Quality of the weather data (pressure/temperature/etc)
- Additional weather/atmospheric extensions

Sample range: [0,31]

6.3 Packet Structure for Packet Type 2 (Tx ID and GPS time along with Partial Trilateration Info)

Table 4: Packet Info for Packet Type 2

Field	bit_index	num_bits
Packet type	1 – 3	3
Reserved bit	4	1
Start bit	5	1
Stop bit	6	1
Payload	7 – 102	96

Table 5: Payload for Packet Type 2

Field	field _id	bit_index	num_txbits
Tx ID	1	1 – 15	15
Tx correction	2	16 – 20	5
Pressure	3	21 – 31	11
Temperature	4	32 – 39	8
Weather info	5	40 – 46	7
GPS time – Week Number	6	47 – 56	10
GPS time – TOW in seconds	7	57 – 76	20
Time offset relative to GPS	8	77 – 86	10
Slot Index	9	87 – 90	4
UTC time offset from GPS	10	91 – 96	6

6.3.1 Descriptions of the fields of packet type 2

Individual MBS service providers should map the raw values of the bits for each field to a range and resolution they feel best meets their requirements. Below are descriptions and sample ranges for each field.

6.3.1.1 Transmitter ID

The Tx ID field must be a unique ID that identifies each transmitter within one major deployment area, such as within North America. With 15 bits, up to 32,768 unique transmitters can be identified. The Tx ID should be used, along with an almanac on the receiver, to extract the lat/long/height of each transmitter, as well as the Tx quality information for each transmitter.

Sample range: [0, 2^15-1]

6.3.1.2 Tx correction

Tx correction is as described in Section 6.2.1.

Sample range: [0,25] ns, 1ns resolution

6.3.1.3 Pressure, Temperature, and Weather info

Pressure, Temperature, and Weather info are as described in Section 6.2.1.

Pressure	Sample range: [94500, 106776] Pa, with 6 Pa resolution
Temperature	Sample range: [228, 329.6] Kelvin, with 0.4 degrees Kelvin resolution
Weather info	Sample range: [0,124]

6.3.1.4 GPS time – Week number & TOW

This represents the GPS time of the R frame immediately preceding the H1/H2 frames in which this packet was carried. GPS time is represented as time of week (TOW) and GPS week number.

TOW is the number of seconds since the beginning of the GPS week, which runs from zero to 604799 at the end of week. The TOW second count returns to zero coincident with the resetting of the GPS PRN codes.

The GPS week number represents the GPS weeks (modulo 1024) since week 0 which started at 00:00:00 Sunday 6th January, 1980.

Week number	Range: [0,2^10-1] weeks, with 1 week resolution
TOW seconds	Range: [0, 604799] sec, with 1 sec resolution

6.3.1.5 MBS time offset relative to GPS

This is the offset of MBS system time relative to GPS time. Note that MBS system time is always delayed relative to GPS time by the number of nano-seconds specified in this field and is expected to be a constant.

Sample range: [0,1000] ns, with 1ns resolution.

6.3.1.6 Slot Index

This is the physical time slot in which a transmitter is transmitting.

Range: [0,9].

6.3.1.7 UTC time offset from GPS

This is the UTC time offset from GPS time. The UTC offset field can accommodate 63 leap seconds (six bits).

Range: [0,63] sec, with 1 sec resolution.

6.4 Additional Packet Types

Additional packets using packet type greater than 2 may be defined as required for the MBS system.

6.5 Periodicity of Packet Type Transmission

The periodicity and the associated time offset of the transmission for various packet types is MBS service provider specific. The packet transmissions of a particular type may be staggered relative to other beacons.

As an example, in the beacon with Tx ID 1 occupying slot 1, the packet with type 2 may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=0 and packet type 0 may be transmitted at all other times. Whereas, in the beacon with Tx ID 2 occupying slot 2, packet type 2 may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=3 and packet type 0 may be transmitted at all other times.

7 Appendix A: Transmit Filter Taps (at 4 samples per chip)

Idx	Filter Tap	Idx	Filter Tap	Idx	Filter Tap
1	-0.000000176795813	27	-0.005032525589647	53	0.003688476821592
2	-0.000105400894759	28	0.000578496047144	54	0.000225006980155
3	-0.000506510439665	29	0.007274083361462	55	-0.002820151710350
4	0.000017926535619	30	-0.001071930604566	56	-0.000154303305525
5	0.000622069897515	31	-0.011446509363444	57	0.002225666433076
6	-0.000020943705042	32	0.002346672474270	58	0.000110028727138
7	-0.000702490451183	33	0.020665533546919	59	-0.001801760932846
8	0.000025153457115	34	-0.006945246406238	60	-0.000081556225106
9	0.000799260255750	35	-0.048569967588775	61	0.001488005612170
10	-0.000030877723955	36	0.046724283110992	62	0.000061814962858
11	-0.000917876978677	37	0.379367282666764	63	-0.001250042945255
12	0.000038128166689	38	0.802942566327759	64	-0.000048246760490
13	0.001064594329818	39	1.000000000000000	65	0.001064594329818
14	-0.000048246760490	40	0.802942566327759	66	0.000038128166689
15	-0.001250042945255	41	0.379367282666764	67	-0.000917876978677
16	0.000061814962858	42	0.046724283110992	68	-0.000030877723955
17	0.001488005612170	43	-0.048569967588775	69	0.000799260255750
18	-0.000081556225106	44	-0.006945246406238	70	0.000025153457115
19	-0.001801760932846	45	0.020665533546919	71	-0.000702490451183
20	0.000110028727138	46	0.002346672474270	72	-0.000020943705042
21	0.002225666433076	47	-0.011446509363444	73	0.000622069897515
22	-0.000154303305525	48	-0.001071930604566	74	0.000017926535619
23	-0.002820151710350	49	0.007274083361462	75	-0.000506510439665
24	0.000225006980155	50	0.000578496047144	76	-0.000105400894759
25	0.003688476821592	51	-0.005032525589647	77	-0.000000176795813
26	-0.000347859335185	52	-0.000347859335185		

8 Appendix B: PN Codes that may be used by MBS

In general, any family of PN codes may be used for MBS. For example, the GPS family of Gold Codes may be used, as shown in the table below. Note that the G2 delay and G2 code initial state in the table below**Error! Reference source not found.** are specified in the same way as in the GPS interface specification IS-GPS-200 Revision E.

Table 6: Sample PN Codes used by MBS, based on GPS family of Gold Codes

G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)
12	201	130	706	235	1076	359	1216
15	1220	135	1156	237	1617	365	1572
16	1510	144	215	238	1707	373	663
21	232	145	1106	248	735	386	450
22	1115	150	1362	260	1400	389	1445
29	1174	153	136	263	540	395	1654
30	476	156	1213	264	260	399	272
34	1523	157	1505	278	1535	405	262
37	1552	159	721	279	656	407	1054
48	1563	163	335	289	1641	422	263
52	267	173	1206	291	1750	438	277
56	213	175	1241	292	764	445	471
68	1007	176	520	298	667	446	1234
72	1740	185	134	307	1312	456	1653
76	376	188	613	309	1662	461	435
79	1637	189	1305	310	731	462	216
83	171	193	1454	314	635	463	107
85	1436	197	462	320	1046	465	421
87	307	202	751	326	1010	467	1104
109	1665	203	364	327	404	476	1003
112	1566	208	1607	333	1004	482	610
118	355	211	1560	339	1050	484	142
121	35	212	1670	345	510	499	1411
122	1016	221	77	355	341	500	604
126	140	225	103	357	1070	503	1460
127	1060	230	1702	358	434	525	72

G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)	G2 Delay	G2 Initial State (Octal)
530	641	663	727	798	1142	894	573
536	746	670	1223	801	1114	900	1045
537	1363	675	1224	807	111	901	1422
539	1674	677	1245	811	1504	904	1542
540	736	684	1735	814	1550	911	436
556	1330	693	1011	815	664	926	1323
567	327	695	1602	816	332	932	1573
568	1153	699	270	818	66	935	1757
580	632	711	1747	819	1033	942	147
586	606	712	1763	836	1277	953	206
595	740	713	771	837	537	955	1441
602	1663	714	374	846	242	957	710
603	1731	729	254	849	1024	959	1562
607	375	732	25	851	205	960	1671
628	1254	740	1230	853	1041	992	1017
632	552	761	521	870	1310	995	501
634	1532	762	1250	877	455	1012	551
644	1570	771	45	879	1113	1015	1455
647	557	780	1160	883	1644	1018	1745
652	753	788	1342	885	1751	1021	1774
653	365	792	256	886	1764		
657	717	797	305	891	1737		

The ‘G2 delay’ referred to in the table above is the delay of the G2 code used in the standard GPS PN Code generation of length 1023. In pseudocode:

```
 y1 = standard_gps_m_sequence1_G1;
 y2 = standard_gps_m_sequence2_G2;
PN_code = xor(y1, circular_shift(y2,delay));
```

9 Security Considerations

The MBS ICD does not itself create a security threat.

10 IANA Considerations

There are no IANA considerations for the MBS ICD.

11 Conclusions

Metropolitan Beacon System (MBS) consists of a network of terrestrial beacons broadcasting signals for positioning purposes. Terrestrial Beacon Systems can be designed to facilitate UE positioning in areas where in-orbit satellite based systems are most challenged, such as indoors, or in dense urban environments and extends UE positioning capabilities in these environments. In addition, MBS enables the delivery of an accurate UE altitude for emergency or commercial services.

12 References

12.1 Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

12.2 Informative References

[GPS ICD] IS-GPS-200, Revision D, Navstar GPS Space Segment Navigation User Interfaces, March 7th, 2006.

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