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Re:	802.16 Rev2 Sponsor Ballot
Abstract	This contribution proposes a correction and improvement of the encoding of the GPS time in the LBS-ADV message.
Purpose	To be discussed and adopted by 802.16 Rev2.
Notice	
Release	
Patent Policy	

Encoding of the GPS time in the LBS-ADV message

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1 Introduction

The GPS Time TLV (11.21.4), which is used to signal GPS time in the LBS-ADV message, does not signal the GPS time in the most efficient way.

The TLV uses 12 bits to signal the GPS seconds modulo 2048 [*sic*] and 28 bits to signal GPS second fraction. An immediate improvement would be to recognize that 12 bits may express an integer modulo 4096 and change the modulus from 2048 to 4096, or reduce the number of bits used to express the number of seconds by 1. When this TLV was introduced into the standard, the assumption was that the SS's clock is sufficiently accurate to determine the time within an hour (3600 seconds) and, thus, the SS would be able to determine the exact number of GPS seconds if the seconds were signaled modulo 4096. However, we propose to use another value for the modulus for the reasons explained below.

Before this TLV got accepted into the standard, two solutions were considered. In the first solution, the BS signals the GPS time of the frame in which the LBS-ADV message is transmitted. In the other solution, which is currently in the standard, the BS signals the GPS time of when it transmitted frame 0 of the current epoch. The second solution was chosen because it was simplest to implement in the BS. In the first solution the BS updates the value of the GPS time TLV every time it is transmitted, whereas in the second solution, the BS must update the value fields in the TLV when the frame number wraps around. Although it is preferable to update the TLV value every time the frame numbers wrap around rather every time the LBS-ADV message is transmitted, it would be even better if one could avoid having to update the TLV value when the frame numbers wrap around. This can be achieved by expressing the GPS time modulo *m*, where *m* divides the frame wraparound period as illustrated by the following example:

Suppose that the BS transmits frame 0 at time *t*, and the frame duration is 5 ms. The frame numbers wrap around $2^{24}\times$ 5 ms later. So after the frame number wraps around, the GPS time TLV will show time $t + 2^{24}\times 5$ ms mod *m*. If $m = 4096$ seconds, then $t + 2^{24}\times 5$ ms mod 4096 s = t + 83886.08 s mod 4096 s = t + 1966.08 s mod 4096 s. The value that is transmitted in the GPS time TLV must be adjusted by 1966.08 seconds every time the frame numbers wrap around. See Figure 1.

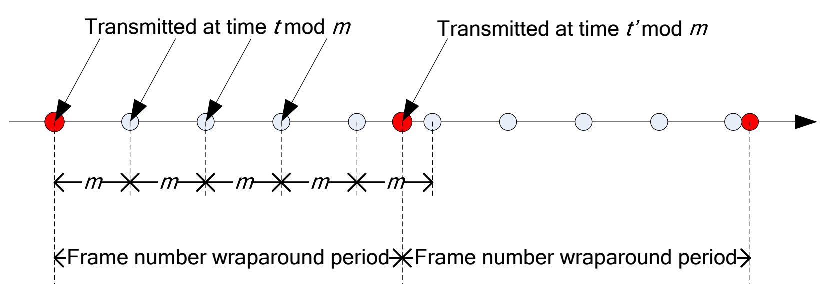

Figure 1: If *m* does not divide the frame number wraparound period

On the other hand, if $m = 2^{22} \times 5$ ms, $t + 2^{24} \times 5$ ms mod $2^{22} \times 5$ ms $= t$, which shows that the same value t continues to be transmitted. See Figure 2.

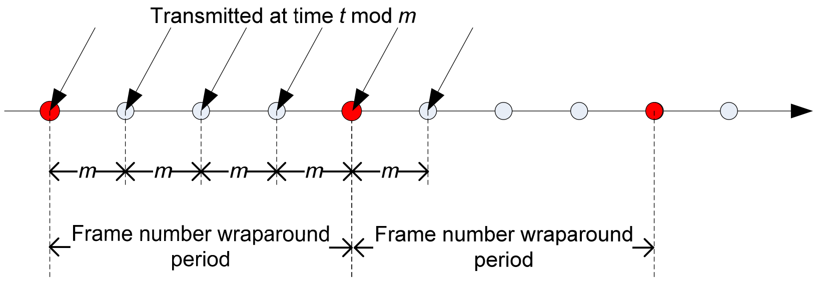

Figure 2: If *m* does divide the frame number wraparound period

We observe that if the BS signals the GPS time modulo the frame number wraparound period (i.e., $2^{24} \times T_f$, where T_f is the frame duration) or modulo any divisor of the frame number wraparound period, the BS would not need to update the value field of the GPS time TLV when the frame number wraps around. Therefore, we propose that the BS should signal GPS time modulo $2^{22} \times T_f$. When $T_f = 5$ ms, the modulus is 20971.52 seconds, which implies that if the MS is capable of determining GPS time by its own clock within approximately +/- 3 hours, 22 bits signaled in the LBS-ADV allows the MS to determine GPS time with an accuracy of 5ms. When $T_f = 0.5$ ms, the modulus is 2097.152 seconds, which implies that if the MS is capable of determining GPS time by its own clock within approximately +/- 17 minutes, 22 bits signaled in the LBS-ADV message allows the MS to determine GPS time with an accuracy of 0.5 ms.

Further, we observe that 28 bits for the fraction of GPS seconds allows one to express the time with a resolution of approximately 3.73 ns ($2^{-28} \cong 3.73 \times 10^{-9}$). The LBS-ADV message is used by BSs that are synchronized with reference to the GPS pulse per second (see 8.2.7.1.1). A BS will signal values close to multiples of T_f. For instance, a system profile may typically require the BS to start frame transmission within 1 microsecond (µs) from an integer multiple of T_f. Therefore, we propose to signal the GPS time as a pair of integers (n_0, k), where $0 \le n_0 < 2^{22}$ signals time in units of T_f modulo $2^{22} \times T_f$, and $-2^9 < k < 2^9$ signals a signed offset in units of 2 ns (i.e., the maximum offset is approximately +/- 1µs). The number k is signaled using 10 bits and two's complement notation. In total, the GPS time within an accuracy of 2 ns can be signaled using 32 bits. The accuracy is signaled using 6 bits as currently specified in the standard.

Example – MS side:

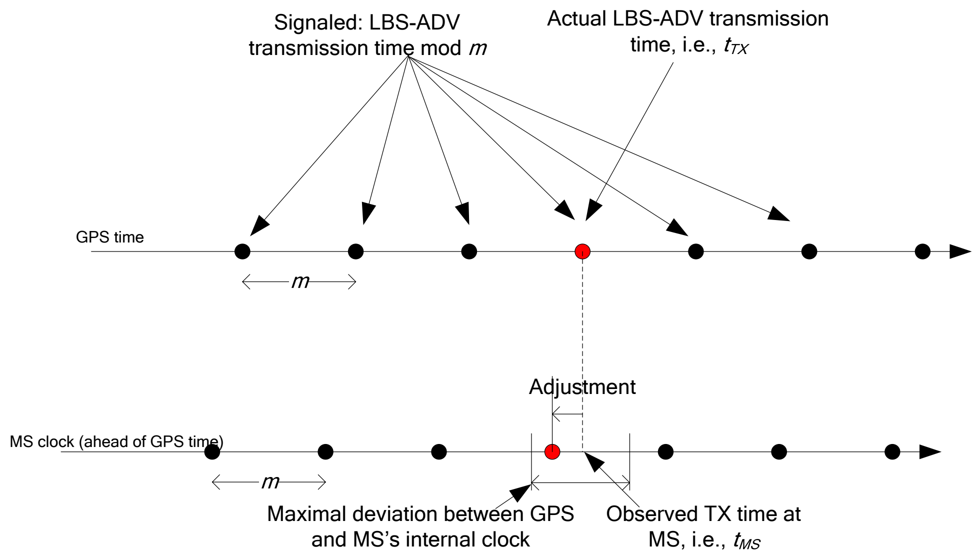

Figure 3: Adjusting the clock at the MS

Assume that the frame duration is 5 ms. The MS' internal clock shows 11:59:59 PM AOE, on September 11th, 2008, when it receives the LBS-ADV message. This time translates to GPS time 1221220799 (Ref. http://www.mapshots.com/tools/gps_time.asp). The LBS-ADV message is transmitted in frame 12345678 and signals the pair (1690652, -150). When the LBS-ADV message is transmitted, the GPS time is $(1690652 + 12345678 + N\times 2^{22}) \times 5\text{ms} - 150 \times 2\text{ns} + \varepsilon$, where ε is bounded by the signaled accuracy. Assuming that the MS' internal clock is accurate within $2^{22}\times 5 \text{ ms} / 2 \approx 10485$ seconds, the number N is calculated as follows:

$$N = \left\lfloor \frac{1221220799\text{ s} - (1690652 + 12345678) \times 5\text{ ms}}{2^{22} \times 5\text{ ms}} + 0.5 \right\rfloor = 58229$$

The GPS time at the BS when the LBS-ADV message was transmitted was 1221220819.729999700 + ε. (The MS' internal clock is almost 21 seconds too slow.)

Example – BS side:

Assume that the transmission time of frame number 12345678 was measured using a GPS reference clock to be 1221220819.73 s when rounded to the nearest multiple of 5 ms. Measurements over time show that the transmission is consistently delayed by 300 +/- 12 ns with respect to exact multiples of 5ms.
The transmission time of frame number 0 is computed to be 1221220819.73 s - 12345678 × 5ms = 1221159091.34 s. The transmission time of frame 0 is computed modulo $2^{22} \times 5$ ms, which yields 8453.26 s = 1690652 × 5 ms. The offset is -150 × 2ns, and the absolute value of the accuracy is less than 2^{14} picoseconds (i.e., $\lceil \log_2(12000) \rceil = 14$). So the BS signals 0x19CC1C for the time in units of 5 ms, 0x36A (= 10-bits two's complement of 0x96) for the offset, and 0x0E for the accuracy.

In general, let:

- t_{TX} be the GPS time of the start of the frame in which the LBS-ADV message is transmitted;
- t_{MS} be the time in units of seconds at the MS according to its internal clock when it receives the LBS-ADV message;
- n_f be the frame number in which the LBS-ADV message is transmitted;
- m be the modulus used, where m divides the frame wraparound time, i.e., m divides $2^{24} \times T_f$.

Then the BS shall signal a pair (n_0, k) and accuracy α, where $n_0 = (\lfloor t_{TX} / T_f + 0.5 \rfloor - n_f) \bmod (m / T_f)$, and $\left|2k \text{ ns} + t_{\mathrm{TX}} - \lfloor t_{\mathrm{TX}} / T_f + 0.5 \rfloor T_f \right| < \alpha$.

If $\left| t_{\mathrm{TX}} - t_{\mathrm{MS}} \right| < m/2$, then $t_{\mathrm{TX}} = (n_0 + n_f)T_f + 2k \text{ ns} + \varepsilon + Nm$, where $N = \left\lfloor \dfrac{t_{\mathrm{MS}} - (n_0 + n_f)T_f}{m} + 0.5 \right\rfloor$ and $\varepsilon < \alpha$.

Note: Assume there is a BS that transmits frame 0 at GPS time 0 mod m. Let us call it the reference BS. The reference BS transmits frame n_0 at time $n_0 T_f$. Compared to another BS$_i$ that transmits frame 0 at time $n_0(i)T_f$, the reference BS is $n_0(i)$ frame numbers ahead mod m. That is, when the reference BS transmits frame n_f, BS$_i$ transmits frame $(n_f - n_0(i))$ mod m. Hence, a number n_f may be used to make an absolute reference to a frame across a network of BSs whose frame numbers are not synchronized: At BS$_i$, the *adjusted frame reference* n_f refers to frame number $(n_f - n_0(i))$ mode m. At any two BSs, the respective frames referenced by an adjusted frame reference n_f are transmitted at the same time. Adjusted frame reference removes the need to impose that BSs have their frame numbering synchronized. For instance, there is no need to impose that all BSs in an MBS Zone have their frame numbering synchronized.

2 Suggested Changes in Rev2/D7

2.1 Remedy - Part 1

[On page 1332, line 36, modify section 11.21.4 as follows:]

11.21.4 GPS Time TLV

This TLV shall be used to provide the GPS time.

Name	Type	Length (bytes)	Value
GPS Time	4	~~6~~5	See Table 609

Table 609—Contents of the GPS Time TLV

Field	Size (bits)	Description
GPS time in units of frame duration ~~Second~~	22~~12 bits~~	GPS time, expressed in units of frame duration T_f ~~second~~, modulo 2^{22} ~~2048~~
GPS frame transmission time offset ~~Second fraction~~	10~~28 bits~~	~~GPS second fraction~~ A signed integer expressing the difference between the OFDMA frame transmission time and the nearest integer multiple of T_f, expressed in units of 2 nanoseconds (ns). Negative values express late transmission. This integer is encoded in two's complement notation. The value 0x200 signals that the offset in absolute value is greater than $(2^9 - 1) \times 2$ ns.
GPS time accuracy	~~8~~ 5 ~~bits~~	This fields encodes an upper bound of the accuracy $\alpha = 2^p$ picoseconds, by providing the binary representation of p. For example, 0b01110 encodes an accuracy less than or equal to $\alpha = 2^{14}$ ps =16.384 ns. Conversely, if the accuracy is 8 ns, a minimal upper bound is encoded by the bit representation of $p = \lceil \log_2(8000) \rceil = 13$, i.e., 0b01101. ~~GPS Time Accuracy For unsigned integer~~

		values 0x00-0x3F: log2(Time error in pico-seconds).
Reserved	3	

In the following equations:

- T_f is the frame duration;
- t_{TX} is the time in units of seconds relative to GPS time (i.e., where time 0 denotes January 6th, 1980, 12:00 AM GMT) of the start time of the frame that carries this TLV;
- t_{MS} is the time in units of seconds at the MS according to its internal clock when it receives the LBS-ADV message;
- n_f is the frame number in which the LBS-ADV message is transmitted;
- m is the modulus used, i.e., $m = 2^{22} \times T_f$.
- n_0 is the value transmitted in the "GPS time in units of frame duration" field;
- k is the value transmitted in the "GPS frame transmission offset" field;
- α is the value transmitted in the "GPS time accuracy" field.

GPS time in units of frame duration

This parameter shall be set to a value n_0, where $n_0 = \lfloor t_{TX} / T_f - n_f + 0.5 \rfloor \mathrm{mod}(m / T_f)$.

GPS frame transmission offset

This parameter shall be set to a value k, where $\left| 2k \text{ ns} + t_{TX} - \lfloor t_{TX} / T_f + 0.5 \rfloor T_f \right| < \alpha$. If $|k| > 2^9 -1$, the BS shall set this field to 0x200.

GPS time accuracy

This parameter shall be set to a value α, where $\left| 2k \text{ ns} + t_{TX} - \lfloor t_{TX} / T_f + 0.5 \rfloor T_f \right| < \alpha$.

The GPS Time TLV informs the receiving MS of the precise time at which the BS transmits frame number 0's First Frame of the current epoch has been transmitted, which the MS may use to calibrate its own internal clock in reference to the GPS time standard. If $\left| t_{TX} - t_{MS} \right| < m / 2$, the MS computes t_{TX} as follows: $t_{TX} = (n_0 + n_f)T_f + 2k \text{ ns} + \varepsilon + Nm$, where $N = \left\lfloor \dfrac{t_{MS} - (n_0 + n_f)T_f}{m} + 0.5 \right\rfloor$, and $\varepsilon < \alpha$.

The GPS Time TLV is used if the BS's frame time is synchronized with the GPS clock., This may be particularly valuable for determining GPS satellite signal search windows in mobiles equipped to detect GPS satellites. GPS second and second fraction frame transmission time offset allows the MS to use DL Frame arrival times as timing signals aligned with GPS time. GPS Time Accuracy aids the MS in estimating how much error with respect to GPS time the BS may have when using this calibration.