**IEEE P802.15**

**Wireless Personal Area Networks**

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| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | Proposed Text Changes to Clock Drift and Guard Time Provisioning |
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| Re: | Sponsor ballot comments. |
| Abstract | This submission provides the proposed resolution for r01-31, r01-32, r01-59, r01-60, and r01-62. |
| Purpose | To facilitate sponsor ballot comment resolution. |
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*Editing Instructions: Incorporate the changes to subclause 7.11 as given below into latest BAN draft, adjusting subclause and figure numbers as appropriate.*

* 1. Clock synchronization and guard time provisioning

A node or a hub shall maintain a MAC clock with a minimum resolution of mClockResolution and with a minimum accuracy of mHubClockPPMLimit to time its frame transmission and reception, except that a node may use a MAC clock with a PPM higher than mHubClockPPMLimit subject to certain restrictions as stated later in this subclause. The node or the hub shall time its transmission and reception in any of their allocation intervals according to its local clock.

The node may request the hub to include a timestamp in an acknowledgment (I-Ack, B-Ack, I-Ack+Poll, or B-Ack+Poll) frame by setting to one the Ack Timing field of a management or data type frame being sent with the Ack Policy field of the MAC header set to I-Ack or B-Ack. The timestamp encodes the start time of the acknowledgment frame transmission based on the hub’s clock. The hub shall include such a timestamp in the acknowledgment frame if and only if requested by the node.

The node shall synchronize to the hub through the beacons, T-Poll frames, acknowledgment frames containing a timestamp, or the first frames (on-time frames) in scheduled allocation intervals received from the hub. In particular, the node shall advance or delay its clock by a total amount of

D = TS – TL, if TS > TL

or

D = TL – TS, if TS < TL

respectively, where TS is the time when such a frame started to be transmitted on the transport medium (i.e., air), and TL is the time when the frame started to be received according to the local clock.

A node may rely on itself or a hub to track and set aside appropriate guard times in its allocation intervals. A hub shall be ready to accommodate either choice, referred to as distributed or centralized guard time provisioning, respectively, as indicated in the node’s last transmitted MAC Capability field.

* + 1. Distributed guard time provisioning

For distributed guard time provisioning, the node and the hub shall include appropriate guard times in the scheduled allocation intervals they requested or assigned, respectively. The hub shall also include appropriate guard times in the polled allocation intervals granted to the node.

* + - 1. Distributed guard time computation

If the node and the hub have the same clock accuracy designated as HubClockPPM in terms of PPM, as shown in Figure 91, the node and the hub shall compute a nominal guard time GTn to compensate for their clock drifts over an interval not longer than a nominal synchronization interval SIn, as follows:

GTn = GT0 + 2×Dn

GT0 = pSIFS + pExtraIFS + mClockResolution

Dn = SIn×HubClockPPM, SIn = mNominalSynchInterval

The parameter GT0 comprises the receive-to-transmit or transmit-to-receive turnaround time pSIFS, the synchronization error tolerance pExtraIFS, and the timing uncertainty mClockResolution, which are all of fixed values that are independent of clock drifts. The parameter Dn represents the maximum clock drift of the node or the hub relative to an ideal (nominal) clock over SIn. The parameter SIn delimits a nominal synchronization interval over which the clock drifts of the node and the hub are accounted for in the nominal guard time GTn.

The node shall further compute an additional guard time GTa to compensate for additional clock drifts of itself and the hub over an interval SIa beyond SIn, as follows:

GTa = 2 × Da, Da = SIa × HubClockPPM

The parameter SIa denotes the length of the time interval that has accrued in addition to SIn since the node’s last synchronization with the hub. The corresponding additional clock drift Da is a function of SIa and accounts for the required additional guard time GTa. The values of Da and SIa are specific to the node and time of concern.

A node may time its frame transmission and reception with a clock accuracy NodeClockPPM larger than HubClockPPM, provided it reduces its nominal synchronication interval to SIn such that

SIn × NodeClockPPM = mNominalSynchInterval× HubClockPPM

If the time interval length SI since its last synchronization with the hub exceeds the reduced SIn by SIa, i.e., if SI = SIn + SIa, the node shall calculate the required additional guard time GTa as follows:

GTa = SIa × NodeClockPPM + min[0, (SI – mNominalSynchInterval)× HubClockPPM]

An illustration of clock drifts and guard times for the case of a hub and nodes operating with the same clock accuracy is given in Figure 91, with the following legend:

Nf = fast node Ns = slow node H = slow hub in (a) and fast hub in (b)

tmH = position of ideal (nominal) clock when NH‘s local clock is at tm, m = 1, .., or 4

tmf = position of ideal (nominal) clock when Nf‘s local clock is at tm, m = 1, .., or 4

tms = position of ideal (nominal) clock when Ns‘s local clock is at tm, m = 1, .., or 4

SIn = nominal synchronization interval GTn = nominal guard dtime

Dn = maximum clock drift over SIn w.r.t. ideal clock

SIa = additional synchronization interval GTa = additional guard time

Da = maximum clock drift over SIa w.r.t. ideal clock

allocation interval of H = allocation interval in which H controls the timing for frame transactions

allocation interval of N = allocation interval in which N controls the timing for frame transactions



(a) Slow hub



(b) Fast hub

1. — Analysis of clock drifts and guard times for distributed provisioning

* + - 1. Distributed guard time compensation

With reference to Figure 91 and Figure 92, and with GTn given in Equation (6), GT0 in Equation (7), SIn in Equation (8) or (10) as appropriate, and GTa in Equation (11), the node and the hub shall account for clock drifts and guard times in their frame transmission and reception as follows:

* The hub shall commence its beacon transmission at the nominal start of the beacon.
* The hub shall commence its transmission in the node’s next scheduled downlink or bilink allocation interval at the nominal start of the interval, and shall end its transmission in the interval early enough such that the last transmission in the interval completes at least GTn prior to the nominal end of the interval.
* The hub shall commence its transmission of the node’s next future poll or post at the nominal start of the poll or post.
* The hub shall commence its reception in the node’s next scheduled uplink allocation interval up to GTn – GT0 earlier than the nominal start of the interval to account for pertinent clock drifts.
* If the node’s last synchronization to the hub was less than SIn ago at the nominal end of its next scheduled uplink or polled allocation interval, the node shall commence its transmission in the interval at the nominal start of the interval, and the node shall end its transmission in the interval early enough such that the last transmission in the interval completes at least GTn prior to the nominal end of the interval.
* If the node’s last synchronization to the hub was less than SIn ago at the nominal start of the next beacon transmission, the node shall commence its reception of the beacon up to GTn – GT0 earlier than the nominal start of the beacon to account for pertinent clock drifts.
* If the node’s last synchronization to the hub was less than SIn ago at the nominal start of its next future poll or post, the node shall commence its reception of the poll or post up to GTn – GT0 earlier than the nominal start of the poll or post to account for pertinent clock drifts.
* If the node’s last synchronization to the hub was less than SIn ago at the nominal start of its next scheduled downlink or bilink allocation interval, the node shall commence its reception in the interval up to GTn – GT0 earlier than the nominal start of the interval to account for pertinent clock drifts. The node may commence its reception up to GTn – GT0 later than the start of the interval based on its estimate of the relative clock drift with respect to the hub since its last synchronization with the hub.
* If the node’s last synchronization to the hub was SIn + SIa ago at the nominal end of its next scheduled uplink allocation interval, the node shall commence its transmission in the interval GTa later than that nominal start time, and shall end its transmission in the interval early enough such that the last transmission in the interval completes at least GTn + GTa prior to the nominal end of the interval.
* If the node’s last synchronization to the hub was SIn + SIa ago at the nominal end of its next polled allocation interval, the node shall commence its transmission in the interval at the nominal start of the interval, and shall end its transmission in the interval early enough such that the last transmission in the interval completes at least GTn + GTa prior to the nominal end of the interval.
* If the node's last synchronization to the hub was less than SIn + SIa ago at the nominal start of the next beacon transmission, the node shall commence its reception of the beacon up to GTn + GTa – GT0 earlier than the nominal start of the beacon to account for pertinent clock drifts.
* If the node’s last synchronization to the hub was less than SIn + SIa ago at the nominal start of its next future poll or post, the node shall commence its reception of the poll or post up to GTn + GTa – GT0 earlier than the nominal start of the poll or post to account for pertinent clock drifts.
* If the node’s last synchronization to the hub was SIn + SIa ago at the nominal start of its next scheduled downlink or bilink allocation interval, the node shall commence its reception in the interval up to GTn + GTa – GT0 earlier the that nominal startof the interval to account for pertinent clock drifts. The node may commence its reception up to GTn + GTa – GT0 later than the start of the interval based on its estimate of the relative clock drift with respect to the hub since its last synchronization with the hub.



(a) Nominal guard time



(b) Nominal guard time and additional guard time

1. — Distributed provisioning of of guard times for frame transmissions
   * + 1. Distributed guard time allocation

The node and the hub shall include a nominal guard time GTn as given in Equation (6) and, if applicable, twice an additional guard time GTa as given in Equation (11) in each of the scheduled allocation intervals they request or assign. The hub shall also include the nominal guard time GTn in each of the polled allocation intervals granted to the node.

* + - 1. Clock synchronization for distributed guard time provisioning

The node shall synchronize with the hub at least once within the nominal synchronization interval SIn given in Equation (8) or (10) as appropriate, if only the nominal guard time GTn as given in Equation (6) is accounted for per 7.11.1.3. The node shall synchronize with the hub at least once within the nominal synchronization interval SIn given in Equation (8) or (10) as appropriate, plus the additional synchronization interval SIa given in Equation (10), if both the nominal guard time GTn as given in Equation (6) and the additional guard time GTa as given in Equation (11) are accounted for per 7.11.1.3.

* + 1. Centralized guard time provisioning

For centralized guard time provisioning, the node shall not include clock drifts or guard times in the scheduled allocation intervals it requests, but the hub shall include appropriate clock drifts in the scheduled allocation intervals it assigns to the node. The hub shall also provision an appropriate guard time between two neighboring allocation intervals one or both of which are assigned to the node requiring centralized guard time provisioning.

* + - 1. Centralized guard time computation

As shown in Figure 93, the hub shall compute a centralized guard time GTc between two neighboring allocation intervals (with beacon treated as an allocation interval), both of which do not include a guard time, to compensate for pertinent clock drifts, as follows:

For case (a) where each of the two allocation intervals is a beacon or an allocation interval in which the hub controls the timing for frame transactions,

GTc = GT0

For case (b) where one of the two allocation intervals is a beacon or an allocation interval in which the hub controls the timing for frame transactions, and the other is an allocation interval in which the node controls the timing for frame transactions, given the node’s maximum synchronization interval SIN and its clock accuracy PN in terms of PPM, and the hub’s clock accuracy PH in terms of PPM,

GTc = GT0 + SIN ×(PH + PN)

For case (c) where one of the two allocation intervals is an allocation interval in which the node controls the timing for frame transactions, and the other is an allocation interval in which another node controls the timing for frame transactions, given the node’s maximum synchronization interval SIN1 and its clock accuracy PN1 in terms of PPM, the other node’s maximum synchronization interval SIN2 and its clock accuracy PN2 in terms of PPM, and the hub’s clock accuracy PH in terms of PPM, with the other node also requiring centralized guard time provisioning,

GTc = GT0 + PN1×SIN1 + PN2×SIN2 + PH×|SIN1 – SIN2|

The parameter GT0 is a fixed value independent of clock drifts as given in Equation (7).

In Figure 93(a), there are no relative clock drifts since it is the same hub that controls the timing for frame transactions in both allocation intervals. In Figure 93(b), since the node last synchronized to the hub SIN ago, the hub’s clock has drifted by DH toward the other allocation interval, and the node’s clock has drifted by DN toward the other direction, both relative to an ideal clock. In Figure 93(c), since the two nodes last synchronized to the hub SIN1 and SIN2 ago, their clocks have drifted by DN1 and DN2 in oppsite directions, respectively; between the times of the nodes’ last synchronization, the hub’s clock has also drifted by DH in the same direction as the clock of the node that synchronized with the hub later, all relative to an ideal clock.

Of the two neighboring allocation intervals, in case the earlier one is provided for distributed guard time provisioning and thus includes a nominal guard time GTn as given in Equation (6) at the end, the hub may deduct GTn from GTc in inserting a centralized guard time between the two intervals. Further, if the earlier one is a scheduled uplink or polled allocation interval provided to a node for distributed guard time provisioning, the hub shall set SIN or SIN1 to SIn as given in Equation (8) in computing GTc according to Equation (13) or (14).

On the other hand, in case the later one is a scheduled downlink, bilink, or uplink allocation interval assigned to a node requiring distributed guard time provisioning, the hub shall treat such an interval as one assigned for centralized guard time provisioning in inserting a centralized guard time between the two intervals. Further, if such an interval is a scheduled uplink allocation interval, the hub shall set SIN or SIN2 to SIn as given in Equation (8) in computing GTc according to Equation (13) or (14), respectively.

An illustration of clock drifts and guard times for the case of both neighboring allocation intervals (with beacon treated as an allocation interval) not including guard times is given in Figure 91, with the following legend:

H = hub N = node N1 = node 1 N2 = node 2

PH = PPM of H’s clock PN = PPM of N’s clock PN1 = PPM of N1’s clock PN2 = PPM of N2’s clock

SIN = maximum synchronization interval of N

SIN1 = maximum synchronization interval of N1

SIN2 = maximum synchronization interval of N2

DH = clock drift of H w.r.t. ideal clock DN = clock drift of N w.r.t.. ideal clock

DN1 = clock drift of N1 w.r.t. ideal clock DN2 = clock drift of N2 w.r.t. ideal clock

GTc = centralized guard time

allocation interval of H = allocation interval in which H controls the timing for frame transactions

allocation interval of N = allocation interval in which N controls the timing for frame transactions



(a) Beacon or allocation interval of H – beacon or allocation interval of H



(b) Beacon or allocation interval of H – allocation interval of N or vice versa



(c) Allocation interval of N1 – allocation interval of N2

1. — Analysis of clock drifts and guard times for centralized provisioning
   * + 1. Centralized guard time compensation

With reference to Figure 93 and Figure 94, and with GT0 given in Equation (7), and GTc in Equation (12), (13), or (14) as appropriate, the node and the hub shall account for clock drifts in their frame transmission and reception as follows, where the node applies Equation (13) to calculate GTc for its reception time:

* The hub shall commence its beacon transmission at the nominal start of the beacon.
* The hub shall commence its transmission in the node’s next scheduled downlink or bilink allocation interval at the nominal start of the interval, and shall end its transmission in the interval early enough such that the last transmission in the interval completes by the nominal end of the interval.
* The hub shall commence its transmission of the node’s next future poll or post at the nominal start of the poll or post.
* The hub shall commence its reception in the node’s next scheduled uplink allocation interval up to GTc – GT0 earlier than the nominal start of the interval to account for pertinent clock drifts since the node last synchronized with it.
* The node shall commence its transmission in a scheduled uplink allocation interval at the nominal start of the interval, and shall end its transmission in the interval early enough such that the last transmission in the interval completes by the nominal end of the interval.
* The node shall commence its reception of the beacon up to GTc – GT0 earlier than the nominal start of the beacon to account for pertinent clock drifts since it last synchronized with the hub.
* The node shall commence its reception in its next scheduled downlink or bilink allocation interval up to GTc – GT0 earlier or later than the nominal start of the interval to account for pertinent clock drifts since it last synchronized with the hub.
* The node shall commence its reception of its next poll or post up to GTc – GT0 earlier than the nominal start of the poll or post to account for pertinent clock drifts, where the node’s last synchronization interval is measured up to the nominal start of the poll or post.



1. — Centralized provisioning of of guard times for frame transmissions
   * + 1. Centralized guard time allocation

The node shall not include clock drifts or guard times in the scheduled allocation intervals it requests. The hub shall include 2×(GTc – GT0) with GTc given in Equation (13) in each of the scheduled downlink or bilink allocation intervals it assigns to the node. The hub shall also provision at least a centralized guard time GTc given in Equation (12), (13), or (14) as appropriate, between two neighboring allocation intervals, minus a nominal guard time GTn given in Equation (6) if the earlier one of the allocation intervals is provided to a node requiring distributed guard time provisioning and hence includes GTn in the end, treating a beacon as an allocation interval that does not include GTn.

* + - 1. Clock synchronization for centralized guard time provisioning

The node shall synchronize with the hub at least once within its maximum synchronization interval SIN as indicated in its last transmitted Connection Request frame.