DETAILED DESCRIPTION

[0037] Some embodiments described herein provide simple and accurate phase and frequency synchronization across wireless links. Methods and systems are described that detect phase variations across wireless links. The proposed methodology may allow for the creation of a phase and frequency synchronized wireless network.

[0038] Some embodiments described herein includes methods and techniques that simplify detection of phase variations over that described regarding IEEE 1588v2 and may, in some embodiments, improve the accuracy of the phase offset calculation. The phase offset calculation may be used for phase synchronization. In some embodiments, a phase offset is calculated as a relative difference between near-end and far-end units and is calculated on both sides of the wireless link independently. In some embodiments, before the offset calculation is calculated, frequency synchronization is completed, and a time protocol counter may be at the data link layer on each side of the wireless link. This application incorporates by reference US nonprovisional patent application serial number 16/046,877, titled "Airframe Timestamping Technique for Point-to-Point Radio Links," filed July 26, 2018.

[0039] As discussed herein, the time protocol counter (e.g., precision time protocol (PTP)) on the data link layer on the near-end side of the wireless channel may be referred to as a "local time protocol counter" and the time protocol counter on the far-end side as a "remote time protocol counter."

[0040] While embodiments described herein may refer to the IEEE 1588v2 standard, it will be appreciated that embodiments described herein may utilize many different standards and many different protocols. In some embodiments, examples will be described showing an improvement over the IEEE 1588 V2 standard. As discussed herein, various techniques may be utilized in place of or in addition to any number of different protocols and standards (e.g., protocols and standards for frequency synchronization).

[0041] Further, as discussed herein, a "unit" may refer to the whole system connecting to other systems either with wired or wireless links.

[0042] If there are any additional time protocol counter(s) (e.g., PTP counters) on the unit (e.g., for timestamping Ethernet packets) then most or all of the time protocol counters (e.g.,

transceiver RFUs 102 and 104 communicate over microwave radio frequencies although it will be appreciated that transceiver RFUs 102 and 104 may communicate over any portion of the wireless spectrum (e.g., not limited to the microwave spectrum).

[0047] Further, although depicted as communicating directly to each other, each of the transceiver RFUs 102 and 104 may communicate via a tower or any other receivers, transmitters, and/or transceivers.

[0048] The transceiver RFU 102 includes a first transceiver, a waveguide 106, and an antenna 108. The transceiver RFU 104 includes a second transceiver, a waveguide 110, and an antenna 112.

[0049] In various embodiments, the transceivers RFUs 102 and 104 may correct for offset and phase utilizing systems and methods discussed herein.

[0050] The transmission over a microwave path may be based on a continuous synchronous transmission of air frames separated by a preamble. FIG. 2 is an example air frame structure 200 in some embodiments. Such a transmission scheme may be called a Constant Bit Rate (CBR).

[0051] In some embodiments, every air frame starts with the preamble 202 which may be a sequence known to the receiver. In this example, the preamble 202 is followed by an Air Frame Link Control field 204, which contains control information defining the air frame 200. In various embodiments, the preamble 202 and the air frame link control field 204 are followed by blocks of QAM (or QPSK) symbols, called transport blocks (TB) 206-216. Transport blocks (e.g., transport blocks 206-216) may be containers for user data (e.g., Ethernet packets, TDM Payload, or the like) and other required control data (e.g., ACM, ATPC, AGC, control loops, or the like) exchanged mutually by microwave modems.

[0052] The size of those containers may depend on the current Adaptive Coding Modulation (ACM) state and on the configured framing choice. Adaptive coding modulation allows dynamic change of modulation and FEC level to accommodate for radio path fading which is typically due to weather changes on a transmission path. Benefits of ACM may include improved spectrum efficiency and improved link availability, particularly in wireless (e.g., microwave) links.

CLAIMS

1. A method comprising:

receiving, by a first physical layer of a first transceiver, a timing packet over an ethernet connection;

timestamping, by the first transceiver, the timing packet and providing the timing packet to a first intermediate node;

receiving, by the first intermediate node, the timing packet from the first transceiver;

determining a first offset between the first intermediate node and the first transceiver;

updating a first field within the timing packet with the first offset between the first intermediate node and the first transceiver, the first offset being in a direction of a second transceiver;

receiving the timing packet by the second transceiver, the timing packet including the first field, information within the first field being at least based on the first offset;

determining a second offset between the second transceiver and an intermediate node that provided the timing packet to the second transceiver; and

correcting a time of the second transceiver based on the second offset and the information within the first field.

2. The method of claim 1, wherein determining the first offset between the first intermediate node and the first transceiver comprises:

receiving, at the first intermediate node, a request airframe from the first transceiver, the request airframe including a first timestamp indicating a first time T1 that the request airframe was transmitted from the first transceiver, the first transceiver and the first intermediate node including first and second counters, respectively;

timestamping, by the first intermediate node, a second time indication indicating a second time T2 that the request airframe was received;

generating a respond airframe and including within the respond airframe a third time indication indicating a third time T3 that the respond airframe is to be transmitted to the first transceiver;

transmitting the respond airframe to the first transceiver;

providing, by the first intermediate node, a timestamp information request to the first transceiver;

receiving a timestamp information response, from the first transceiver, in response to the timestamp information request, the timestamp information response including a fourth time indication indicating a fourth time T4 when the respond packet was received by the first transceiver;

calculating, by the first intermediate node, the first offset using the first time, the second time, the third time, and the fourth time as follows: $first\ offset = \frac{(TS1+TS4-TS3-TS2)}{2}$.

3. The method of claim 2, wherein the first and second counters are synchronized with each other before the first offset is calculated.

4. The method of claim 2, wherein the first counter is a Precision Time Protocol (PTP) counter.

5. The method of claim 2, further comprising determining asymmetry (ASY) in a wireless link between the first transceiver and the first intermediate node, wherein calculating the first offset includes $\frac{(TS1+TS4-TS3-TS2)}{2} \pm \frac{Asy}{2}$.

6. The method of claim 2, further comprising:

providing the timing packet by the first intermediate node to a second intermediate node;

receiving, at the second intermediate node, a request airframe from the first intermediate node, the request airframe including a first timestamp indicating a first time T1 that the request airframe was transmitted from the first intermediate node;

timestamping, by the second intermediate node, a second time indication indicating a second time T2 that the request airframe was received;

generating a respond airframe and including within the respond airframe a third time indication indicating a third time T3 that the respond airframe is to be transmitted to the first intermediate node;

transmitting the respond airframe to the first intermediate node;

providing, by the second intermediate node, a timestamp information request to the first intermediate node;

receiving a timestamp information response, from the first intermediate node, in response to the timestamp information request, the timestamp information response including a

fourth time indication indicating a fourth time T4 when the respond packet was received by the first intermediate node;

calculating, by the second intermediate node, a third offset using the first time, the second time, the third time, and the fourth time as follows: $third\ offset = \frac{(TS1+TS4-TS3-TS2)}{2}$; and

updating the first field within the timing packet with the third offset between the second intermediate node and the first intermediate node, the third offset being in the direction of the second transceiver.

7. The method of claim 6, wherein the second intermediate node is the intermediate node that provided the timing packet to the second transceiver.

8. The method of claim 7, further comprising determining asymmetry (ASY) in a wireless link between the second transceiver and the intermediate node that provided the timing packet to the second transceiver, wherein calculating the third offset includes $\frac{(TS1+TS4-TS3-TS2)}{2} \pm \frac{Asy}{2}$.

9. The method of claim 1, wherein the first transceiver and the second transceiver have synchronized frequencies.

10. The method of claim 1, wherein the updating the first field within the timing packet with the first offset between the first intermediate node and the first transceiver is $TS_{TLV}[i] = TS_{TLV}[i-1] + off_{TC_{i+1}}$ wherein the first field is a TLV, TS is a timestamp, and off is the first offset.

11. The method of claim 10, further comprising the first transceiver updating the first field as follows $TS_{TLV}[1] = TS_{in} + off_{TC_2}$.

12. The method of claim 11, wherein the second transceiver calculates a residence time based on a time of the timing packet calculated at a physical layer of the second transceiver and the information of the first field, as follows $\Delta T_{res} = TS_{out} - TS_{TLV}$.

13. The method of claim 12, wherein the second transceiver updates a clock based on the residence time as follows $\Delta T_{res} = TS_{out} - TS_{TLV}$.

14. A system comprising:

a first transceiver configured to receive, by a first physical layer, a timing packet over an ethernet connection and configured to timestamp the timing packet;

a first intermediate node configured to receive the timing packet from the first transceiver, determine a first offset between the first intermediate node and the first transceiver, and update a first field within the timing packet with the first offset between the first intermediate node and the first transceiver, the first offset being in a direction of a second transceiver; and

the second transceiver configured to receive the timing packet, the timing packet including the first field, information within the first field being at least based on the first offset, configured to determine a second offset between the second transceiver and an intermediate node that provided the timing packet to the second transceiver, and configured to correct a time of the second transceiver based on the second offset and the information within the first field.

15. The system of claim 14, wherein the first intermediate node configured to determine the first offset between the first intermediate node and the first transceiver comprises the first intermediate node configured to receive a request airframe from the first transceiver, the request airframe including a first timestamp indicating a first time T1 that the request airframe was transmitted from the first transceiver, timestamp a second time indication indicating a second time T2 that the request airframe was received, generate a respond airframe and include within the respond airframe a third time indication indicating a third time T3 that the respond airframe is to be transmitted to the first transceiver, transmit the respond airframe to the first transceiver, provide a timestamp information request to the first transceiver, receive a timestamp information response, from the first transceiver, in response to the timestamp information request, the timestamp information response including a fourth time indication indicating a fourth time T4 when the respond packet was received by the first transceiver, and calculate, by the first intermediate node, the first offset using the first time, the second time, the third time, and the fourth time as follows: $first\ offset = \frac{(TS1+TS4-TS3-TS2)}{2}$.

16. The system of claim 15, the first intermediate node being further configured to assist to determine asymmetry (ASY) in a wireless link between the first transceiver and the first intermediate node and to calculate the first offset using $\frac{(TS1+TS4-TS3-TS2)}{2} \pm \frac{Asy}{2}$.

17. The system of claim 15, further comprising a second intermediate node, the second intermediate node configured to receive the timing packet from the first intermediate node, receive a request airframe from the first intermediate node, the request airframe including a first timestamp indicating a first time T1 that the request airframe was transmitted from the first intermediate node, timestamp a second time indication indicating a second time T2 that the request airframe was received, generate a respond airframe and include within the respond airframe a third time indication indicating a third time T3 that the respond airframe is to be transmitted to the first intermediate node, transmit the respond airframe to the first intermediate node, provide a timestamp information request to the first intermediate node, receive a timestamp information response, from the first intermediate node, in response to the timestamp information request, the timestamp information response including a fourth time indication indicating a fourth time T4 when the respond packet was received by the first intermediate node, calculate a third offset using the first time, the second time, the third time, and the fourth time as follows: $third\ offset = \frac{(TS1+TS4-TS3-TS2)}{2}$, and update the first field within the timing packet with the third offset between the second intermediate node and the first intermediate node, the third offset being in the direction of the second transceiver.

18. The system of claim 17, wherein the second intermediate node is the intermediate node that provided the timing packet to the second transceiver.

19. The system of claim 18, wherein the second intermediate node is further configured to assist to determine asymmetry (ASY) in a wireless link between the second transceiver and the intermediate node that provided the timing packet to the second transceiver and to calculate the third offset using $\frac{(TS1+TS4-TS3-TS2)}{2} \pm \frac{Asy}{2}$.

20. The system of claim 14, wherein the first intermediate node is configured to update the first field within the timing packet with the first offset between the first intermediate node and the first transceiver as $TS_{TLV}[i] = TS_{TLV}[i-1] + off_{TC_{i+1}}$
wherein the first field is a TLV, TS is a timestamp, and off is the first offset.

21. The system of claim 20, the first transceiver being further configured to update the first field as follows $TS_{TLV}[1] = TS_{in} + off_{TC_2}$.