Multimedia Clock Synchronization over IEEE 802.11 WLAN

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I. INTRODUCTION

The rapid development in portable computing platforms, distributed multimedia systems and wireless communication technologies has led to a significant interest in mobile multimedia and wireless networking. Video entertainment and multimedia Internet access over wireless networks are some examples of future wireless personal communication systems. These however incur challenging technological issues. The synchronization of the multimedia objects among mobile clients is one of the most important issues that need to be solved.

In this paper, we propose an efficient multimedia synchronization algorithm for IEEE 802.11 Wireless Local Area Networks (WLAN) and mobile multimedia systems. We discuss the novel algorithm and provide its formal proof and correctness. The goal is to achieve synchronization of wireless multimedia systems with an accuracy in the order of 100 ns. This level of accuracy is required to enable professional quality audio and video applications over wireless. Note that the 802.11 Time Synchronization Function defined in [3] provides an accuracy of ±2 μs. The proposed algorithm can be adopted with a very few changes of the current 802.11 Medium Access Control (MAC) defined in [3] without modifying the core MAC functions. The mechanism described in this paper has been already adopted by the IEEE 802.11 working group (WG) in the current IEEE 802.11e D5.0 [4]. This mechanism has been also adopted by the IEEE 1394 wireless working group (WWG) to synchronize Wireless 1394 nodes connected via 802.11e WLAN.

II. MULTIMEDIA CLOCK SYNCHRONIZATION SERVICE

The cycle master (CM) is defined as the single source of the clock synchronization throughout the network. Every node in a wireless network should be synchronized with the CM. If the nodes are connected via 802.11 WLAN, it is necessary to define a protocol to accurately synchronize the wireless nodes as well as wireless bridges with the CM (see Figure 1 in the context of 1394 wireless nodes connected via 802.11 WLAN).

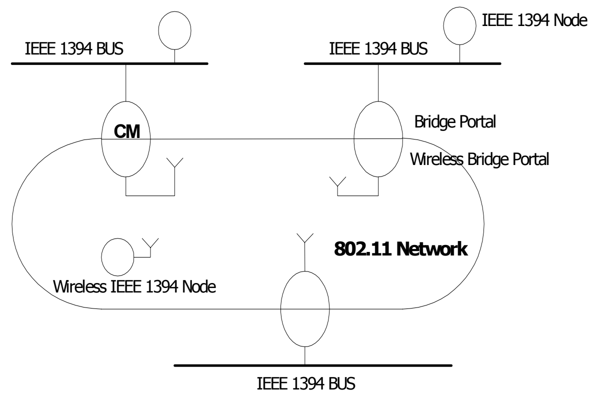

Figure 1. IEEE 802.11 network connecting bridge and non-bridge 1394 devices

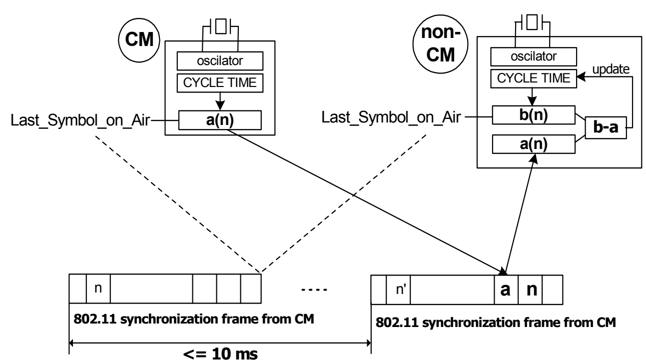

Figure 2. Multimedia Clock Synchronization principle

For simplicity of the explanation, we assume that the CM is one of the wireless bridges. The frames sent by the CM will serve as the reference for the synchronization of the rest of the nodes as follows (see Figure 2).

A. Operation of the CM

The CM sends a *synchronization frame* with a period smaller than or equal to an appropriate value, e.g. 10 ms, to achieve an accurate synchronization among wireless nodes. Note that it does not need to be exactly periodic for the proposed mechanism to work properly. Actually, it is not possible to transmit such frames exactly periodically in 802.11 WLAN. This frame will be identified by its Source Address (SA), i.e., the MAC address of the CM and its Destination Address (DA), which will be a specific multicast address reserved for this purpose. Note that this synchronization frame is transmitted as a data type frame by the 802.11 WLAN MAC.

When the CM detects the event referred to as *Last_Symbol_On_Air* of the transmitted *synchronization frame,* which corresponds to the end of the last symbol of the frame on the air, as indicated by the physical (PHY) layer (details given below), the CM saves the value of the CYCLE TIME value as a(n) where n is the sequence number of the frame (corresponding to the 2-octet Sequence Control field of the 802.11 MAC frame [3]).

B. Operation of Wireless Nodes

When the non-CM wireless nodes detect the *Last_Symbol_On_Air* event of a *synchronization frame* sent by the CM, the wireless nodes save the value of its CYCLE TIME as b(n), where n is the sequence number of the frame received.

The next synchronization frame sent by the CM will contain the values a(n) and n. The time difference between b(n) and a(n) is used to adjust the CYCLE TIME register of the non-CM wireless node.

C. Detection of the Last Symbol on the Air

For the correct operation of the system, it is necessary that both the CM sending the synchronization frame, and the wireless nodes, receiving the frame, detect the end of the last symbol of the synchronization frame on the air at the same time.

The detection of the last symbol in the air will be informed to both the MAC and the multimedia application by the PHY. We assume that the propagation delay over the air is negligible.

In the CM:

The PHY indicates to the MAC that the end of the transmission of the synchronization frame has occurred. The PHY utilizes the mechanisms already provided in [3], that is, the PHY_TXEND.confirm signal.

The multimedia application must take into account delays from the PHY Layer to the application, and hence, it must consider that the indication from the PHY layer arrives with a certain fixed offset. Therefore a(n) is adjusted as follows:

$$a(n) = CYCLE\_TIME_{\text{(at observed PHY\_TXEND.confirm)}} - offset_a$$

where *offset* is the difference between the time that PHY.TXEND.confirm is observed by the application layer and the time corresponding to the end of the last symbol of the transmitted frame on the air. The $offset_a$ is fixed in an implementation and known a priori by the implementer.

In non-CM Wireless Nodes:

The presence of the last symbol on the air will be announced by the PHY using the PHY_RXEND. indication [3]. Adjusting the delay as above:

$$b(n) = CYCLE\_TIME_{\text{(at observed PHY\_RXEND.indication)}} - offset_b$$

where $offset_b$ is the difference between the time that PHY.RXEND.indication is observed by the application and the time corresponding to the end of the last symbol of the received frame on the air.

In both cases, the offset from the PHY to the application is fixed and can be known for a specific implementation.

III. Conclusions

In this paper we have provided a mechanism to synchronize wireless multimedia nodes connected via IEEE 802.11 WLAN. The method has been evaluated by the IEEE 1394 WWG, and concluded that it can achieve synchronization within ±100 ns. As a result, this mechanism has been already adopted by the IEEE 802.11e in the IEEE 802.11e D5.0 [4], and by the IEEE 1394 WWG. We expect that this mechanism can be used by any multimedia application requiring a tight synchronization over 802.11 WLAN, e.g., to solve the "lip-synch" problem between TV and wireless speakers and to synchronize speakers of a home theater system.

IV. References

[1] IEEE P1394.1/D1.0 Draft Standard for High Performance Serial Bus Bridges. June 2001.

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[3] IEEE Std 802.11-1999, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications,* Reference number ISO/IEC 8802-11:1999(E), IEEE Std 802.11, 1999 edition, 1999.

[4] IEEE 802.11e/D5.0, *Draft Supplement to Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS),* November 2002.