Enabling Seamless WiGig/WiFi Handovers in Tri-band Wireless Systems

Yao-Yu Li, Chi-Yu Li, Wei-Han Chen, Chia-Jui Yeh, Kuochen Wang
Department of Computer Science, National Chiao Tung University, Hsinchu, Taiwan

***Abstract*—WiGig enables wireless multi-gigabit communication over 60GHz band. However, its usage scenarios may be constrained by two major limitations: line-of-sight propagation and very short transmission range. We seek to boost the WiGig's usability by using WiFi to complement its limitations in tri-band (2.4/5/60GHz) wireless systems. Our goal is to let a tri-band client have multimedia services at the WiGig's very high speed without any hassle. When the WiGig link is down or performs bad, not only can the client temporarily handover to WiFi without service interruption, but its ongoing multimedia services can also adapt to the WiFi's slower link. Though the IEEE 802.11ad standard has proposed an FST (Fast Session Transfer) mechanism to support handover operations at the link layer, it does not satisfy our goal due to two reasons. First, it does not specify when to perform WiGig/WiFi handovers. Second, it is not application-aware to achieve the service adaptation. To this end, we design and implement an application-aware, seamless WiGig/WiFi handover solution above the network layer. It ensures timely handover trigger for the WiGig's abrupt link interruption, keeps service continuity during handovers, and adapts multimedia service qualities to different WiGig/WiFi links. Our demo confirms its viability. We show that a video streaming service at the client is not interrupted during WiGig/WiFi handovers, which are triggered by mobility or the WiGig's signal blockage, but smoothly switches between different resolutions according to different links.**

I. Introduction

The WiGig technology, which is based on IEEE 802.11ad standard [1], enables wireless communication at multi-gigabit speeds. It delivers data rates up to 7 Gbps with minimal latencies over unlicensed 60GHz frequency band, which is allowed for much larger channel bandwidths than current WiFi. It can enable emerging devices/applications that have high throughput demands, such as wireless docking stations, wireless AR/VR head-mounted displays, multimedia applications requiring high resolution and low latency, etc.

In this work, we explore to enable WiGig/WiFi cooperation to boost the WiGig's usability for multimedia services. It is motivated by two reasons. First, the WiGig has two major limitations due to its millimeter wave (mmWave) propagation characteristics: a short communication range only up to 10 meters and line-of-sight propagation, where signals cannot penetrate walls or objects. They may result in service interruption in case of mobility or signal blockage, thereby thwarting the WiGig's usability. Second, tri-band devices, which are equipped with both 2.4/5GHz WiFi and 60GHz WiGig, are proliferating [2]. There have been some tri-band chipsets [3], [4] and devices [5], [6] in the market.

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We aim to employ WiFi to complement the WiGig's limitations so that the tri-band client can have uninterrupted multimedia services even if the WiGig link is intermittent. Since the WiGig mostly has greater throughput than the WiFi, the quality of ongoing services may need to be adapted when different links are used. For example, the client can have services with high-resolution and low-resolution videos over the WiGig and the WiFi links, respectively. This goal calls for an application-aware, seamless WiGig/WiFi handover solution.

There are two major issues to enable the handover solution. The first is when to trigger the WiGig/WiFi handovers can minimize the impact on the client's ongoing services, especially for the WiGig's abrupt link interruption caused by a sudden signal blockage. The second is how to prevent an ongoing data session from being interrupted during the handovers, and make its application be aware of link changes and thus adapt the content. Though an FST (Fast Session Transfer) mechanism is proposed by the 802.11ad standard [1] to support WiGig/WiFi handover operations at the link layer, it does not address these two application-oriented issues.

Several studies [7], [8], [9], [10] have been proposed to examine the performance of WiGig/mmWave, but they are unable to achieve seamless WiGig/WiFi handover. A survey [7] presents the mmWave communication's characteristics, limitations, and potential applications. Two works [9], [10] improve WiGig throughput by enabling double-link beam tracking and concurrent transmissions, respectively. The other study [8] experimentally characterizes the WiGig's TCP performance.

II. Design

We propose a seamless WiGig/WiFi handover solution above the network layer, different from the FST's link-layer approach, and enable it to feedback handover events to multimedia applications. It mainly achieves two goals for a tri-band client which associates with a tri-band AP. First, the client can handover timely when its WiGig link deteriorates, breaks, or recovers. Second, not only can the client's ongoing services be kept during handovers, but the application servers which accept the handover feedbacks can also adapt to different links. Our solution includes three major features below.

Client-based Handover. The client determines when to trigger handovers based on the conditions of its WiGig/WiFi links. To trigger a handover, the client sends a signaling message with the request to the AP through its WiFi link. Meanwhile, the client notifies ongoing multimedia application servers of the handover if there is any. In order to prevent signaling

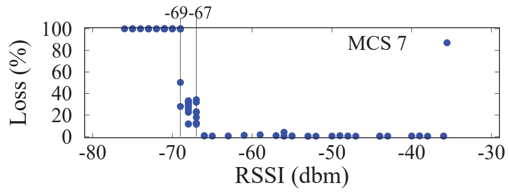

Fig. 1. Packet loss rate increases as RSSI decreases when MCS 7 is used.

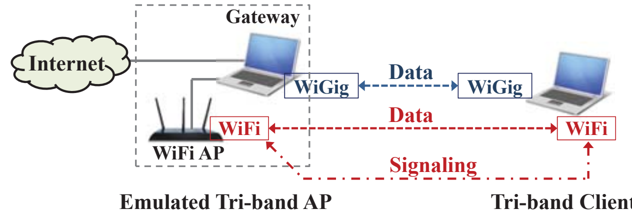

Fig. 2. Our Tri-band wireless system.

messages from being congested by other WiFi traffic, they are given higher priority by the 802.11e [11]. When receiving the handover request, the AP switches the client's data traffic from the current link (i.e., WiGig or WiFi) to the other.

Cross-layer Handover Trigger. The network-layer handover between WiGig and WiFi networks is determined based on the WiGig's link-layer information, i.e., RSSI (Received Signal Strength Indicator). This cross-layer design can timely trigger the handover when the WiGig link suffers or recovers. Our experimental results show that the region of the RSSI transition between applicable and inapplicable conditions is stable and very narrow, since the 60GHz band has very less interference. Figure 1 shows that the transition region is only 3dbm for the rate MCS7. The WiGig's link quality can thus be gauged based on RSSI values. Note that we did the experiments by putting the client at different locations and times.

Virtual Networking. We employ a virtual network interface at the client to hide the WiGig/WiFi handovers from applications. The traffic forwarding between the virtual interface and WiGig/WiFi networks is mediated based on handover triggers. It can prevent IP changes for ongoing data sessions.

III. Experimental Platform and Implementation

We implement our solution using commercial off-the-shelf devices, as shown in Figure 2. We emulate the tri-band AP using one WiFi AP and one laptop equipped with a WiGig NIC, which is a USB dongle with the Tensorcom WiGig chipset [12]. The laptop serves the roles of both a gateway and a WiGig AP. The gateway interconnects the WiFi/WiGig AP and the Internet. The tri-band client is one laptop with both WiGig and WiFi NICs. Note that the WiGig module is a low-power solution with two transmit/receive antennas and digital beamforming support. It can operate in two WiGig channels (i.e., 2 and 3) with maximum physical rate 1.9 Gbps (i.e., MCS7).

We deploy a module at each of the client and the AP. The client module keeps monitoring the WiGig's RSSI, and triggers a handover when the RSSI value becomes higher or lower than a threshold (-65dbm in our demo). To initiate a handover, the client module modifies the local routing table for uplink traffic, and sends signaling messages to the AP module or/and application servers with ongoing data sessions. Afterwards, the AP module updates local routing table for the client's downlink traffic and the application adapts its content.

IV. Demonstration

We demonstrate our WiGig/WiFi handover solution by streaming a video to the tri-band client from a video server next to the emulated tri-band AP. During WiGig/WiFi handovers, which are triggered by moving the client inside and outside the WiGig coverage, the video stream is not interrupted but has only resolutions change. In order to show the WiGig's high throughput and low latency, we use uncompressed video streams in the demo. When the WiGig is used for data delivery, an uncompressed video with 1280x720 resolution at 60 frames per second is streamed via UDP and needs average 260 Mbps network bandwidth. When the WiFi is used, we choose an uncompressed video with very low resolution 320x180, which requires only average 20 Mbps bandwidth. It is because we seek to show obvious resolutions change in the demo. Our demo video can be viewed online [13][1].

We want to note two things. First, the WiGig module does not support rate adaptation, so we fix the rate to be MCS7. It can achieve maximum UDP throughput 960 Mbps with large frame size (e.g., 7180 bytes), but only 350 Mbps can be obtained with the video's smaller frame size (i.e., 1000 bytes). Second, our result shows that the average handover delay is around 3 ms in both handover directions. The delay is measured from the time that a handover request is sent, to the time that the client receives the first data packet through the new link. It takes less than 1 ms for the AP to process each handover event and the remaining time of the handover delay is spent on the delivery of the signaling and data packets.

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[1]Due to the software we use to record screens in Ubuntu, the animation has a little lag but is smooth on the scene.