RT-WiFi: Real-Time High Speed Communication Protocol for Wireless Control Systems

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Due to their enhanced mobility and reduced configuration and maintenance cost, wireless control systems (WCSs) are widely used in process and vibration control systems, on medical devices, unmanned vehicles and robotics. However, most literatures in WCSs focus on monitoring and low speed control, and less effort has been made on high speed WCSs. It is because most existing wireless communication protocols cannot provide real-time and reliable communication links with preferable high speed by taking energy saving into consideration.

In our current joint project [1], between University of Texas at Austin and University of California, Berkeley, we are building a network-based human rehabilitation system to provide wire-free rehabilitation at local site and bio-feedback and remote mobility for tele-rehabilitation. In this system, sensors, controllers, and actuators are distributed in different locations and connected over high speed wireless networks. In order to achieve real-time motion control, high sampling rate and reliable communication links are critical, which brings great challenges to the wireless protocol design. Fig. 1 demonstrates the result of how sampling rate could affect the performance of a human rehabilitation system. In this simulation, the nominal model of the rehabilitation device in [1] was employed as the controlled plant and a PD (Proportional plus Derivative) controller was implemented. The reference was set as a unit square signal with the frequency of $2Hz$. As shown in Fig. 1, higher sampling rate leads to smaller overshoot and shorter settling time. The result also indicates that a motion control system usually prefers sampling rate higher than $1kHz$ to guarantee good tracking performance. However, current commercially available wireless technologies cannot be directly applied to the high speed WCSs. For example, wireless protocols designed for low-power personal area networks including Bluetooh, ZigBee and WirelessHART do not provide sufficient data rate to support sampling rate as high as $1kHz$. On the other hand, although Wi-Fi offers enough data rate, it does not have any timing guarantee on packet delivery and it is not designed to be energy efficient.

To address this problem, in this work we propose Real-Time WiFi (RT-WiFi) which is a real-time high speed wireless communication protocol. At the very bottom, RT-WiFi adopts physical layer of Wi-Fi in order to support high data rate. On top of that, we are hacking MAC (medium access control) layer of Wi-Fi to adopt TDMA (Time Division Multiple Access) for providing real-time data delivery and to explore the channel diversity. Fig. 2 shows the architecture of a wire-free human rehabilitation system at local site. The wireless station and the access point here are Linux boxes, each equipped with Atheros AR9285 Wi-Fi card. The duration of each time slot is set as $500\mu s$, so that we can achieve a data rate of $2kHz$ which is sufficient for a wide range of wireless control applications. In order to provide reliable communication, RT-WiFi utilizes channel hopping and channel blacklists mechanisms to avoid interference, and it supports acknowledgment and retransmission to further improve reliability. Moreover, since the sensors and actuators in WCSs are usually attached at battery-powered mobile devices, RT-WiFi takes an energy-efficient design by turning on its wireless radio only in time slots when transmitting or receiving is scheduled, and it aggressively puts devices in power saving mode to minimize energy consumption.

With the design goal to support reliable, real-time, and high speed communication, we envision RT-WiFi can serve as an ideal platform to high speed WCSs. By adjusting the data rate of RT-WiFi, our wireless platform can support a wide range of WCSs and achieve good balance among sampling rate, reliability, and energy efficiency.

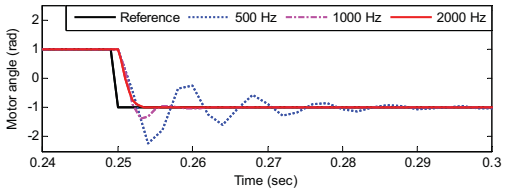

Figure 1: Tracking performance of PD control systems with selected sampling rates (partial amplification)

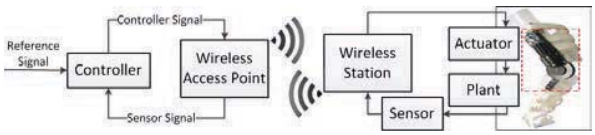

Figure 2: Conceptual block diagram of the human rehabilitation system

1. REFERENCES

[1] W. Zhang, X. Zhu, S. Han, N. Byl, A. K. Mok, and M. Tomizuka. Design of a network-based mobile gait rehabilitation system. In *IEEE Robotics and Biomimetics (ROBIO)*, 2012.