Fabric Serial Bus: A Serial Bus Network for E-Textile Platform

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ABSTRACT

E-textile provides lots of benefits as a wearable computing platform. However, lack of a proper network protocol for conductive textiles has been hindering development of more intelligent e-textile products. In this paper, requirements on e-textile network are introduced and used to design Fabric Serial Bus (FSB) protocol. This protocol has unique features of automatically detecting signal properties and baud rate on conductive yarn based serial bus. And these features allow dynamic rate adaptation to changes in electrical properties of flexible but vulnerable conductive yarns. Experimental results show that e-textile modules using FSB network can operate under more than 25% variation in line resistance by finding a new feasible baud when signal delay change is alerted.

1. INTRODUCTION

Desires for ubiquitous and pervasive computing have enabled technological growth in mobile and wearable computing over past decades. Small and powerful microprocessors have been introduced to the market and mobile communication infrastructure, such as wireless LAN or HSDPA(high-speed downlink packet access), is available everywhere. However, integrating a number of intelligent services in a compact and comfortable device had been a big challenge that often causes depreciation for a mobile computing product in the market.

A number of researches on wearable computing tried to overcome spatial limitations by using a "truly" wearable platform, i.e. garments. Georgia Tech Wearable Motherboard and Virginia Tech's Hokie Suit were among the first to integrate textile and computing [1][2]. Lilypad Arduino by Buechley was successful in commercializing DIY kit for creating electronic textiles [3]. E-textile platform provides additional benefits such as ability to collect personal information from various parts of the wearer's body [4].

Despite all the benefits of e-textile platforms, most commercial e-textile products are equipped with rather simple functions. Bio shirts from NuMetrex and Vital Jacket specialize in gathering wearer's biological information and iPod jackets from various fashion vendors specialize in controlling iPod using textile buttons. In order to design a next generation intelligent e-textile garment with more integrated functionalities, we need inner hardware modules that are small and flexible as well as a proper communication network to connect them. Simple and easy way to connect two modules within the same textile would be RS-232 which is supported by most embedded processors and microcontrollers. However, RS-232 only provides 1:1 connection and number of communication lines will increase with additional hardware modules. Park et al. introduced paradigm of fabric as a computing platform by embedding a mesh of network in fabric [1]. Nakad et al. proposed a token-based e-textiles network which focused on fault-tolerant characteristics on a mesh of conductive fibers [5].

In this paper, requirements on communication network for e-textile platform will be described and our Fabric Serial Bus protocol will be proposed and evaluated through experiments.

2. REQUIREMENTS ON E-TEXTILE NETWORK

Requirements on an e-textile network come from two viewpoints of e-textiles. First, as a fashion wear, an e-textile network needs to meet following requirements [6][7].

- *Conductive Textile*: Communication medium used to connect two modules in an e-textile platform should have same physical characteristics as regular textiles. Garments with embedded conductive yarn should look and feel as regular garments.
- *Wearability*: In terms of clothing, e-textiles device should withstand number of collisions and frictions that may occur during wearer's regular activities. It may gradually lose its functionality.
- *Fashionable*: E-textile components should not impose restrictions on materials and fabrication methods used to create garments. Visibility of hardware modules and connections should be minimized.

Second, as an intelligent computing device, an e-textile network needs to meet following requirements [7].

- *Nodes*: Number of nodes to be placed in an e-textile varies with its functions and architecture. We believe an e-textile network should support over 64 node connections. Each node must be plug-and-playable.

- *Topology*: To minimize visibility and improve robustness to mechanical interactions, number of connections should be reduced. Among many network topologies, bus is a good candidate that satisfies the minimal connection requirement.
- *Traffic*: Various types of data traffic would exist on e-textile network: for sensors gathering wearer's biological or physical information would require little bandwidth while some multimedia modules may generate a burst of traffic.
- *Fault-Tolerance*: Conductive textiles are flexible but vulnerable to external forces. An e-textile network should be able to maintain its operation when electrical properties of its connection are degraded by such elements or even when a line breaks.

3. FSB PROTOCOL

In this section, specifications of Fabric Serial Bus (FSB) and its first prototype design will be introduced.

3.1. FSB specifications

Feature specifications of FSB protocol are as follows:

- *Operating Voltage*: Noise environment of e-textile platform is less harsh compared to cars or industrial machines. Hence, FSB hardware may operate on logic voltage level to reduce number of power supplies.
- *Protocol Weight*: Protocol should be light enough to be embedded in low-cost microcontrollers. Often times, e-textile hardware modules have limited computing resources.
- *Number of Wires*: FSB operates with two wires carrying differential signals, D+ and D-. It allows higher communication speed than single-ended one. Asynchronous operation eliminates the need for clock signal. Half-duplex operation is sufficient for e-textile network requirements.
- *Serial Bus Topology*: To minimize number of wires and size of connectors, FSB uses a serial bus topology.
- *Auto Packet Baud Detection*: Each e-textile module, connected on a single bus, has different bandwidth requirements. In order to accommodate all types of network traffic, FSB receiver should be able to auto-detect baud of each incoming packet and receive data. This feature is also crucial for medium adaptation and plug-and-playability.
- *Medium Adaptation*: Fashion requirement on e-textile implies that garment designers should be given freedom to choose any means available for making clothes or textile based accessories as long as it satisfies conductive textile requirement. Different types of conductive yarns have significant differences in their electrical conductivity. Hence, physical layer FSB protocol should be able to auto-detect electrical properties of connections when plugged and adapt to variations in line conductivity.

3.2. Overall architecture

Overall architecture of our first version of FSB protocol MAC/PHY hardware is shown in Figure 1. FSB prototype is composed of transceiver and controller. SPI was chosen as temporary interface to access FSB prototype. Two FSB transceivers are connected to a pair of conductive yarns on a textile that serves as a signal bus.

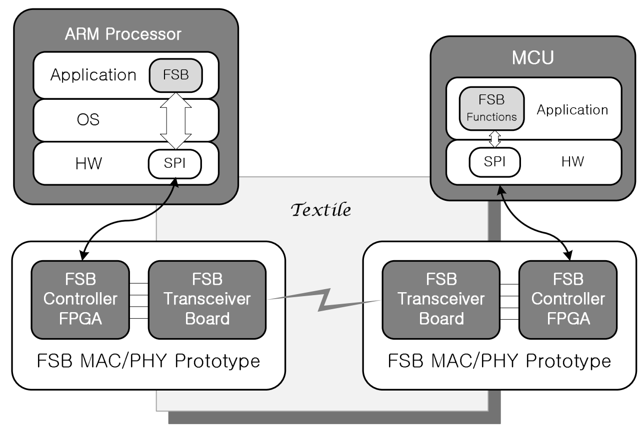

Figure 1. Overall architecture of FSB

3.3. FSB controller

FSB controller is a serial bus controller with *auto packet baud detection* functionality. The design consists of SPI slave interface, internal registers, interrupt control, packet generator, serializer-deserializer (Ser-Des), and additional components for *auto packet baud detection*. The packet generator pads some patterned bits in the header which is used by Ser-Des to extract baud of each packet in real-time manner. Another role of FSB controller is to pass on signal delay measurement from FSB transceiver to host processors. It is implemented in a commercial FPGA running at 50MHz.

3.4. FSB transceiver

FSB transceiver (shown in Figure 2) provides primary functions of transceivers such as differential serial bus access, link status monitoring and error detection, and provides an additional feature of measuring signal delays in received signals.

In order to obtain such measurements, FSB transceiver is equipped with pre-amplifier that increases voltage range of differential signals and adjusts DC bias. Output signal from pre-amplifier is fed to pre-processing block to generate two identical signals with phase difference proportional to signal delay. Upon detection of special padding bit pattern in packet header, controller notifies such event and feeds transceiver with a clock. Transceiver measures signal delay using this clock and reports a five bit value that represents signal delay in terms of this clock.

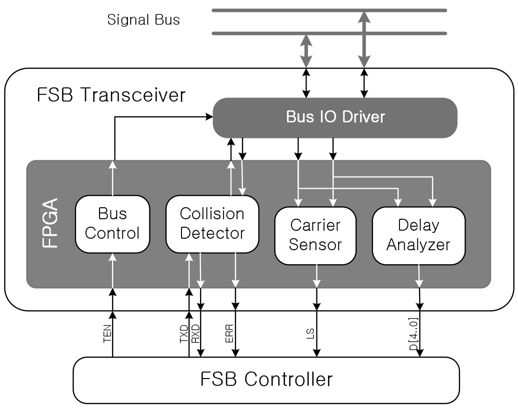

Figure 2. FSB transceiver architecture

4. EXPERIMENTAL RESULTS

In [8], Chung et al. showed that conductive yarn with 10μm thick copper filament with line resistivity of 7.5Ω/m can deliver Ethernet signal up to 9.7Mbps. However, such metal filament yarns give a limited flexibility in garment design because they cannot be sewn, cut or welded in a convenient manner. Conductive yarns with better manufacturability often have lower conductivity and a network for e-textile platform should function on any conductive yarns. Two experiments were conducted to measure performances of various serial protocols on a conductive yarn and compare our FSB over conventional RS-485.

4.1. Serial Communication on Conductive Yarn

The first experiment measured the performance of a number of widely used serial communication protocols, and the result revealed electrical properties of conductive yarns that are different from conventional communication medium.

Figure 3 shows rate of successful communication with a pair of one meter long conductive yarns using three difference serial protocols. Ajin Electron's N6D-210-A silver-coated nylon yarn was used for the experiment. Line resistance varies with each sewn traces and are around 800Ω to 1.2kΩ per meter. The result shows that success rate drops vertically as baud rate is increased beyond some point. At these points, bit transitional delays caused by large line resistance and stray input capacitance significantly degrades signal shapes and transceivers can no longer reconstruct transmitted data.

Various RS-485 transceiver products support different bandwidths and the one in this experiment supports up to 10Mbps. High performance transceivers tend to have lower stray capacitances and higher slew rates which explains high success rate up to 12.5Mbps, however, e-textile modules connected on a serial bus network in parallel tend to increase stray capacitances and worn out conductive yarns tend to increase line resistances. As a result, every communication protocols will experience failure beyond some baud rates and these occurrences will vary in time as well.

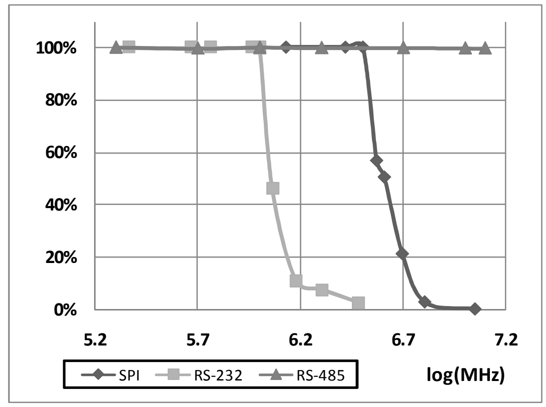

Figure 3. Transmission success rates of three serial protocols

4.2. Dynamic Adaptation to Medium Variation

In order to *plug-and-play* e-textile modules and operate with time-varying medium, FSB protocol should be able to analyze properties of received signals which can be used to determine maximum achievable baud rates. The second experiment demonstrates how *delay analyzer* in FSB transceiver and *auto packet baud detector* in FSB controller can work together to dynamically adapt to medium variation.

For comparison, we first look at two nodes connected using RS-485 physical layer protocol. To diversify experimental environment, we add additional stray capacitances that simulates idle e-textile modules attached (or plugged) to the network. Two sets of three lines shown in Figure 4 represent simulated number of idle modules. A pair of one meter long N6D-210-A yarns with line resistance between 800Ω and 1.2kΩ was used for connection. When silver coated filaments in these yarns break due to external forces, their line resistances will increase. Breaking a filament is an irreversible process; hence we modified lengths of connections as an alternative. Through the manual iteration process, transmission success rates were measured for different baud rates on different line resistances.

The result in Figure 4 shows that when line resistance is increased, previously configured baud rates may become infeasible. Some well designed upper layer protocols could use software timer and monitor increasing bit error rates to predict current situation. However, there is no

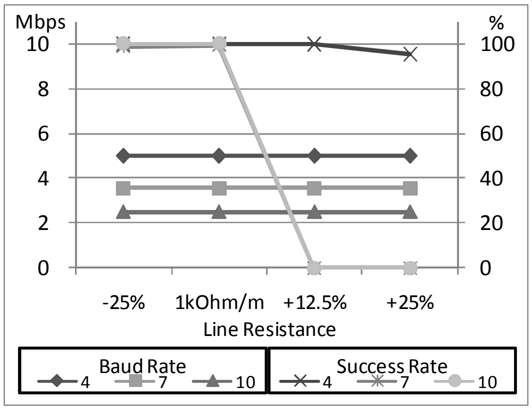

Figure 4. Performance of RS-485 w.r.t. medium variation and number of modules in network

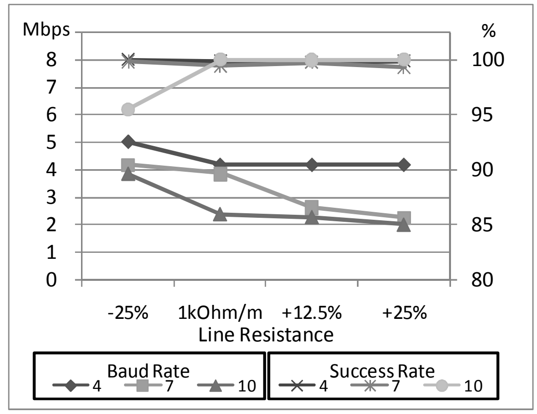

Figure 5. Performance of FSB w.r.t. medium variation and number of modules in network

guarantee when two nodes will find a new feasible baud rate.

Using FSB protocol, receiver node can be alerted whenever received signal delay changes so that the node can notify to the sender. In such notification, receiver may choose to use a new lower baud rate (without previous handshake with sender), because FSB controllers can automatically detect bauds of each packet from its header and reconstruct transmitted data transparently.

The results in Figure 5 show transmission success rates and chosen baud rates. Three lines in each set refer to the number of simulated idle e-textile modules attached to the network. As line resistance increases, change in signal delay is alerted and application chooses calculate a new feasible baud from delay value. Baud rates decrease slightly in most cases, however, transmission success rates remain close to 100%. Rare cases of increasing line resistance may occur when an e-textile user decides to repair worn out connections with new conductive yarns. In such cases, FSB network can make use of connection capacity to obtain more network resource.

6. CONCLUSIONS

In this study, we have proposed a new serial bus network for e-textile platforms. The network requirements on e-textile are different from those on conventional wired/wireless network and our Fabric Serial Bus (FSB) is designed to meet such requirements. First version of proposed FSB protocol hardware and software was implemented to be tested and compared to RS-485, which is a popular light-weight physical layer protocol for serial buses. FSB's ability to analyze signal properties and automatic baud rate detection of each packet allows dynamic adaption to flexible but time-varying connections within e-textile platforms. Experimental results showed that FSB can operate even when line resistance varies more than 25% of its original.

Integrating FSB in small microcontrollers for e-textile platform will bring users a simple and robust e-textile network which will allow development of more e-textile products and intelligent garments. As a future work, FSB will be implemented as a single module to be tested on various kinds of conductive textiles including different conductive yarns and conductive ink circuits.

7. ACKNOWLEDGEMENT

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