Journal of King Saud University – Computer and Information Sciences (2017) **29**, 449–461

King Saud University

Journal of King Saud University – Computer and Information Sciences

www.ksu.edu.sa
www.sciencedirect.com

An Efficient Route Maintenance Protocol for Dynamic Bluetooth Networks

Sabeen Tahir [a,b,*], Sheikh Tahir Bakhsh [a], Abdulrahman H. Altalhi [a]

[a] *Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah 21589, Makkah, Saudi Arabia*
[b] *Department of Computer and Information Sciences, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia*

Received 13 April 2016; revised 28 July 2016; accepted 28 July 2016
Available online 1 August 2016

KEYWORDS

Bluetooth network;
Route maintenance;
Weak links;
Prediction;
Backup device

Abstract Bluetooth is a widespread technology for small wireless networks that permits Bluetooth devices to construct a multi-hop network called scatternet. Routing in multi-hop dynamic Bluetooth network, where a number of masters and bridges exist creates technical hitches. It is observed that frequent link disconnections and a new route construction consume extra system resources that degrade the whole network performance. Therefore, in this paper an Efficient Route Maintenance Protocol for Dynamic Bluetooth Networks (ERMP) is proposed that repairs the weak routing paths based on the prediction of weak links and weak devices. The ERMP predicts the weak links through the signal strength and weak devices through low energy levels. During the main route construction, routing masters and bridges keep the information of the Fall Back Devices (FBDs) for route maintenance. On the prediction of a weak link, the ERMP activates an alternate link, on the other hand, for a weak device it activates the FBD. The proposed ERMP is compared with some existing closely related protocols, and the simulation results show that the proposed ERMP successfully recovers the weak paths and improves the system performance.

1. Introduction

Bluetooth specification is designed for the low power two-way radio communication to connect the network devices over short distances (Chih-Min and Yin-Bin, 2014). The Bluetooth physical layer operates on the 2.4 GHz Industry Scientific and Medical (ISM) frequency band. The key advantage of the ISM frequency band is that it makes the Bluetooth technology accepted worldwide (Laharotte et al., 2015). A Bluetooth device can play the role of a master, slave or bridge. A Bluetooth basic networking unit is called a piconet which behaves like a cluster in an ad-hoc network topology that contains the maximum of eight Bluetooth active devices out of 256 devices.

* Corresponding author at: Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah 21589, Makkah, Saudi Arabia.
E-mail addresses: stsheikh@kau.edu.sa (S. Tahir), stbakhsh@kau.edu.sa (S.T. Bakhsh), ahaltalhi@kau.edu.sa (A.H. Altalhi).
Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksuci.2016.07.003
1319-1578 © 2016 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University.

In a piconet, one Bluetooth device becomes a cluster head known as a master device and other devices become slaves. Within a piconet, direct slave to slave links are not allowed and all communicating links go through the master device. A master device treats the slave devices in a Round Robin (RR) fashion that basically overcomes the collision between devices (Singh and Agrawal, 2011).

To decrease the interference between devices, Bluetooth technology uses the Frequency-Hopping Spread Spectrum (FHSS) Jin-Ho et al., 2014; Subhan et al., 2012 technique. The use of FHSS makes the Bluetooth technology less susceptible to signal congestion and eavesdropping than other wireless technologies. Each Bluetooth device uses 79 channels using a pseudo-random hopping sequence. Each Bluetooth device uses a running clock, and all slave devices stay synchronized to the piconet from time to time adding a timing offset to their clocks from the clock of the master (Etxaniz and Aranguren, 2015). In a Bluetooth network, each active slave device is also allocated a 3-bit Active Member Address (AM_Addr) by the master device. Bluetooth devices discover each other and make the connections. Initially, all the devices are in standby mode only the native clock (CLKN) runs. The Bluetooth clock monitors the timing and hopping sequence of the transceiver, it is typically executed as a 28-bit wrap-around counter (Yu and Lin, 2012; Sharafeddine et al., 2012).

The master sends requests to the other Bluetooth devices to make a piconet. Devices which agree to make a piconet reply to the master's request. The master device sends the ID packets on different frequencies and waits for the reply packets called Frequency Hopping Sequence (FHS) packets from the slave devices. The device sends not only a FHS packet but also its ID and clock value. A Bluetooth device in the inquiry scan mode decreases its hopping frequency; this mode gives consent to the inquirer to catch up with the transmit frequency of the Bluetooth device which is in the inquiry scan mode (Ramana Reddy et al., 2010; Yu, 2010). As the frequencies match, the scanned devices behave like slave devices and transmit their ID and clock information to the master device. The time interval between the starting of two consecutive page scan operations is considered as the scan interval time, $T_{inquiry\_scan}$, that should be less than or equivalent to 2.56 s (Cui et al., 2010). When Bluetooth devices exceed more than eight devices, they make a scatternet (Subhan et al., 2011). A scatternet is a combination of interconnected piconets where a device of one piconet (master/slave) elects to contribute as a slave in other piconets. This intermediate device is called a bridge/relay device that relays the data between piconets. By using this approach, more interconnected piconets can make a large network (Xin and YuPing, 2009) as shown in Fig. 1.

There are many Bluetooth multi-hop routing protocols which have been proposed for inter-piconet communication, but it has been analyzed that none of them consider the route breakage issue (Bo et al., 2012; Yu, 2012; Aldabbagh et al., 2015a,b; Tahir and et al., 2013). Most of the researchers proposed ideas for route optimization without considering route breaking issues. It is true that if the main routing link breaks, it creates some serious problems like delay, unnecessary energy consumption, packet loss, etc. Therefore, it has provided an opportunity to propose an Efficient Route Maintenance Protocol for Dynamic Bluetooth Networks. The proposed protocol overcomes the problem of frequent link breakage and provides a solution in terms of predicting weak links.

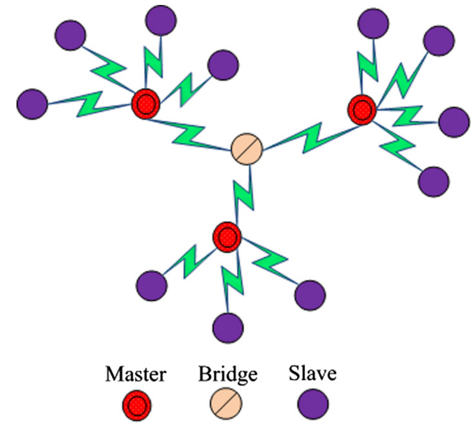

Figure 1 Bluetooth scatternet where one bridge device links three piconets.

The remaining portion of this paper is organized as follows. Section 2 discusses the related work of the proposed protocol. To overcome the frequent link breakage problem, the proposed protocol is presented in Section 3. The performance analysis of the proposed protocol and its comparison with a few similar protocols is shown via simulation in Section 4 using the NS-2 (The NS-2 Simulator, 2014) and UCBT (Agrawal and Wang, 2007). Finally, the conclusion and possible future work is presented in Section 5.

2. Background and related work

In a piconet, direct slave to slave communication is not possible so all communicating links (outgoing and incoming) data traffic go through the master device; therefore, the master is the most important device. If a master device goes down or moves, it may disconnect all linked devices. Similarly, within a scatternet, direct master to master communication is not possible as they always need an intermediate bridge device, therefore, the bridge device is considered as the most significant device because it connects multiple piconets (Ching-Fang and Shu-Ming, 2008). If it fails or moves, then it can disturb the whole network. When data are routed between two Bluetooth networks for slave to slave communication, it follows the rule that the data will go through "slave-to-master – bridge-master-slave". Although, many researchers have proposed different ideas for routing and scatternet formation for a Bluetooth network, but in this research, we considered only the most relevant protocols.

The authors proposed a dynamic energy-aware network maintenance (DENM) protocol Bakhsh and et al., 2011, where a master device maintains a table storing all the connected slave devices' information. When the energy level of the master device reaches L_1, it activates an auxiliary master from its slave devices. Similarly, if a bridge device energy level reaches L_1, it sends a request message to the connected master devices for backup relay activation. This technique provides flexibility against frequent link discussion based on the energy level. The main drawback with this technique is that it does not consider device mobility which can cause frequent link disconnection. The DENM is explained through Fig. 2(a), where source device A transmits data to the destination device D passing