CIR-BASED BEST-ROUTE PREDICTION AND ADAPTIVE MODULATION FOR ROUTING IN OFDM-BASED AD HOC WIRELESS NETWORKS

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Above all else, I would like to thank the Almighty God, for it is under His grace that we live, learn and flourish.

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Abstract

In order to facilitate communication within an ad hoc wireless network, a routing protocol is required to route data between nodes. The primary goal of such routing protocol is to guarantee the correct and efficient information exchange between the nodes. In the respect, one of the critical issues to be tackled for achieving routing efficiency is the channel quality among the devices, which may sometimes being ignored in some of the ad hoc wireless routing protocols. Such practice can be a severe shortcoming as the varying channel quality can lead to very poor overall route quality which in turn result in high error rate and low data throughput.

This research work tries to approach the stated issue from the Physical Layer (PHY) perspective of an Orthogonal Frequency Division Multiplexing (OFDM) broadband ad hoc wireless network. It proposes two wireless routing schemes, namely, the Adaptive-All and Adaptive-Select Routing Scheme, for routing data over the OFDM network. The schemes cover the scope of (a) best-route prediction, and (b) adaptive modulation, based on the channel quality, which is measured by its Channel Impulse Response (CIR). The best-route prediction algorithm determines the best route with the least Bit Error Rate (BER) expected. Through the selected best route, adaptive OFDM modulation is performed towards each OFDM sub-channels for data transmission over the route.

These schemes are formulated with the objective to improve network performance of an OFDM broadband ad hoc wireless network, through the reduction
of BER, and improvement of data throughput. Extensive simulation results show that the proposed schemes achieve the stated goal. As a whole, this research work succeeds in producing two Physical-Layer-based components of ad hoc routing, i.e. the best-route prediction algorithm and the adaptive modulation mechanism, which can be further extended to form a new wireless ad hoc routing protocol, or incorporated into other well-known ad hoc routing protocols, for achieving better routing efficiency in OFDM-based broadband network.
Abstrak

Untuk membolehkan komunikasi dalam rangkaian wayarles "ad hoc", protokol perutean adalah diperlukan untuk menghantar data di antara nod. Tujuan utama protokol perutean tersebut adalah untuk memastikan pertukaran maklumat di antara nod dapat dilakukan dengan tepat dan efisien. Memandang dari segi tersebut, satu daripada isu kritikal yang perlu diatasi bagi mencapai efisien perutean ialah kualiti saluran di antara nod, yang adakalanya diabaikan oleh protokol perutean wayarles ad hoc. Amalan tersebut boleh menjadi satu masalah yang serius kerana kualiti saluran yang sering berubah boleh menghasilkan kualiti rute yang teruk secara keseluruhan dan seterusnya mengakibatkan kadar ralat yang tinggi dan data thruput yang rendah.

Kerja penyelidikan ini cuba meninjau isu tersebut daripada perspektif Lapisan Fizikal (PHY) bagi rangkaian wayarles jalur lebar ad hoc berasaskan "Orthogonal Frequency Division Multiplexing" (OFDM). Ia mengusulkan dua protokol perutean wayarles, iaitu, "Adaptive-All" dan "Adaptive-Select" Skim Perutean, bagi menghantar data dalam rangkaian OFDM. Skim tersebut merangkumi skop (a) ramalan rute-terbaik, dan (b) modulasi adaptif, berdasarkan kualiti saluran, yang diukur oleh "Channel Impulse Response" (CIR). Ramalan rute-terbaik menentukan rute terbaik, iaitu rute dengan jangkaan kadar ralat bit ("Bit Error Rate" (BER)) terendah. Dengan rute terbaik yang dipilih, modulasi adaptif OFDM akan dilaksanakan di dalam setiap sub-saluran OFDM, bagi penghantaran data melalui rute tersebut.
Skim tersebut dibina atas tujuan untuk meningkatkan prestasi rangkaian wayarles jalur lebar ad hoc OFDM, melalui pengurangan BER, dan peningkatan data thruput. Keputusan simulasi menunjukkan bahawa skim berkenaan mencapai matlamatnya. Secara keseluruhan, kerja penyelidikan ini berjaya menghasilkan dua komponen bagi protokol perutean rangkaian wayarles ad hoc, iaitu algoritma ramaian rute-terbaik dan mekanisme modulasi adaptif, di mana komponen tersebut boleh dikembangkan untuk membentuk protokol perutean rangkaian wayarles ad hoc yang baru, atau digabungkan dengan protokol perutean rangkaian wayarles terkini, bagi mencapai efisien perutean di dalam rangkaian jalur lebar berasaskan OFDM.
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CHAPTER 1 INTRODUCTION

1.1 Background

The wireless arena has been experiencing exponential growth in the past decade. We have seen great advances in network infrastructures, growing availability of wireless applications, and the emergence of omnipresent wireless devices. A major goal of such wireless evolution is the provision of pervasive and ubiquitous computing environments that can seamlessly support users in accomplishing their tasks, in accessing information or communicating with other users at any time, anywhere, and from any device.

In general, wireless networks can be classified into two broad categories based on the underlying network architecture:

(a) Infrastructure-based networks: A network with pre-constructed infrastructure that is made of fixed and wired network nodes and gateways, with typically, network services delivered via these pre-configured infrastructure. For example, cellular networks are infrastructure-based network; built from Public Switched Telephone Network (PSTN) backbone, mobile switching center, base stations and mobile hosts.

(b) Ad hoc (Infrastructureless) network: An ad hoc network is a transient network formed dynamically by a collection of arbitrarily located wireless nodes without the use of existing network infrastructure or centralized administration (Liu & Chlamtac, 2004). There is no pre-arrangement regarding the specific role each node should assume. Instead, each node makes its decision independently, based on
the network situation. For example, two PCs equipped with wireless adapter cards can set up an independent network whenever they are within the transmission range of one another.

Ad hoc networks are expected to become an important part of the pervasive computing environment because they help realizing network services for users in areas with no existing communication infrastructure. It enables independent wireless nodes, each limited in transmission and processing power, to be "chained" together to provide wider networking coverage and processing capabilities. These operative advantages make ad hoc networking an attractive option in the following applications scenario:

(a) *Wireless Local Area Network (WLAN)*: Several wireless stations communicate directly within a local area, such as corporate and campus building to exchange information.

(b) *LAN extension*: The wireless nodes are connected to a fixed backbone network through an access point.

(c) *Emergency situations*: Circumstances like searching and rescue as well as other military operations in remote areas, where fixed or cellular network is not available.

(d) *Wireless Sensor Network (WSN)*: Tens or hundreds of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions.

(e) *Wireless Personal Area Network (WPAN)*: Bluetooth-based WPAN that provide universal short-range wireless intercommunication between various peripherals.
Figure 1.1 depicts various wireless applications in the aspects of their ad hoc operation and multi-hopping. Fully decentralized radio, access, and routing technologies enabled by Bluetooth, IEEE 802.11 ad hoc mode, Packet Radio Network (PRnet) stationless mode, mobile ad hoc network (MANET), PAN and PAN-to-PAN communication fit right into the ad hoc domain (right part of the figure).

1.2 Problem Statement

Despite the attractive benefits of ad hoc wireless network, it inherits a number of research challenges, such as bandwidth allocation and power control, dynamically changing network topology, variation in channel quality and etc. Among these research challenges, ad hoc wireless routing protocol has become one of the most active and significant research topics. A routing protocol is required to route data between nodes, in order to facilitate communication within an ad hoc wireless

Figure 1.1: Wireless applications in the aspects of ad hoc operation and multi-hopping (source: Frodigh et al., 2000)
network. The primary goal of such routing protocol is the correct and efficient route establishment between nodes so that data can be routed in an accurate and timely manner. As such, it must be seriously designed to suit the specific needs of ad hoc network environments and characteristics.

One of the critical considerations or challenges in designing an ad hoc wireless routing protocol is the incorporating of the channel quality among the nodes into the routing mechanism. The channel quality among nodes in a wireless environment is usually time varying in nature, due to the signal propagation effects such as path loss and multipath propagation. This phenomenon is clearly observed especially in mobile nodes. In most of the existing ad hoc routing works, minimum-hop-count or the shortest path is used as the criterion in selecting the best route for forwarding data. This minimum hop-count routing algorithm may choose the route that have significantly less capacity than the best path that exist in the network (Couto et al., 2003). The channel quality issue may sometimes being ignored, let alone exploited in some of the ad hoc routing protocols. Such practice can be a serious defect as the varying channel quality can lead to very poor overall route quality which in turn result in high error rate and low data throughput. This drawback is widely stated in Couto et al. (2003), Lin et al. (2002a, 2002b, 2003, 2005) and Gui (2007).

1.3 Research Objective

This research is carried out with the objective to improve network performance of an OFDM-based broadband ad hoc wireless network, through adaptive routing schemes in tackling the channel quality issue. The scheme addresses
the routing operation from the Physical Layer (PHY) perspective where the channel characteristic is used as the routing metric. The objective statement of the schemes can be stated as follows:

(a) The reduction of error rate through best-route selection, and

(b) The aggregated improvement of symbol or bit error rate and data throughput by the means of adaptive OFDM modulation.

This research work employs adaptive OFDM modulation to tackle for the fluctuating wireless channel issue as stated in the problem statement. Adaptive OFDM modulation is an efficient scheme to increase the transmission rate by changing the channel modulation scheme according to the estimated Channel State Information (CSI). The goal of the adaptive modulation is to maximize the data throughput performance and maintain the acceptable BER performance (Ahn & Sasase, 2002). In this adaptive operation, if a particular range of frequencies suffers from interference or attenuation, the sub-channel within that range can be disabled or made to run slower by applying more robust modulation. This adaptive OFDM modulation technique is further elaborated in Chapter 2 (Section 2.3.4).

In these proposed schemes, both best-route selection and adaptive modulation process are based on the channel condition, which is denoted by the Channel Impulse Response (CIR) associated with each wireless link. The efficiency of the scheme can be evaluated by the Bit Error Rate (BER) and data throughput in transmission. Achieving the above-mentioned objective, this research work will contribute towards improving the performance of broadband ad hoc wireless networks such as IEEE.
802.11a, IEEE 802.11g and HiperLAN2, where OFDM is adopted in the underlying PHY Layer.

1.4 Scope / Relevance of Study

This research activity aimed to investigate the routing issue from the PHY Layer perspective by using the CIR as the measurement criteria for routing operation. The work focuses mainly on the topic of best-route selection and adaptive modulation, but not on the overall design of a complete ad hoc wireless routing protocol, which may implies a great extent of scope that beyond the time and effort required in this level of study. The best-route prediction and adaptive modulation formulated in this dissertation can be served as an integrating component to any new routing protocol, or to be a "plug-in" to any existing routing protocol. In this work, some assumption are made as below:

(a) The set of possible routes from the source to the destination node is assumed to be prior-known, i.e. the route discovery and maintenance process is assumed done beforehand.

(b) The CIR is assumed to be available, where the OFDM system has carried out the channel estimation.

(c) The proposed schemes are targeted for a slow time-varying wireless channel, where the coherent period of the channel is relatively long and the CIR can be easily derived and exploited in both time and frequency domains. The environment is assumed to be satisfying the conditions outlined in the Stanford University Interim-3 (SUI-3) Channel Model (Erceg et al., 2001). This SUI-3 channel is further described in Chapter 4 (Section 4.1.3).
(d) Each possible route from the source to the destination node is assumed to have a same number of hops. The selection of best route is merely based upon the channel quality of each hop along the route, where the hop count factor is not incorporated. This is to ease performance comparison as well as performing a fair evaluation.

(e) The computational complexity of the proposed schemes is not evaluated / tested, by which it may become an issue in the real life wireless environment, due to the energy-constraint of the wireless nodes.

1.5 Dissertation Outline

This dissertation is organized as follows:

Chapter 2 provides the review of the relevant concepts and previous works related to the formulation of the Adaptive-All and Adaptive-Select Routing Schemes investigated in this dissertation. It commences with an overview of ad hoc wireless networks, highlighting the associated ad hoc wireless routing protocol. Several literatures on well-known ad hoc wireless routing protocol were reviewed. On the other hand, this chapter also gives some ideas of the nature of OFDM system, mainly in the aspect of OFDM principles and adaptive modulation. Furthermore, the multipath propagation phenomenon and CIR of wireless channel is described.

Chapter 3 contains the description of the Adaptive-All and Adaptive-Select Routing Schemes formulated in this work. The chapter begins with the rationale of formulating the proposed schemes based on the wireless channel quality, i.e. the CIR. The Adaptive-All and Adaptive-Routing Schemes are then described in greater details.