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Simulation methodology and performance analysis of network coding based transport protocol in wireless big data networks

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The Multi-Path, Multi-Hop (MPMH) communications have been extensively used in wireless network. It is especially suitable to big data transmissions due to its high throughput. To provide congestion and end-to-end reliability control, two types of transport layer protocols have been proposed in the literature: the TCP-based protocols and the rateless coding based protocols. However, the former is too conservative to explore the capacity of the MPMH networks, and the latter is too aggressive in filling up the communication capacity and performs poorly when dealing with congestions. To overcome their drawbacks, a novel network coding scheme, namely, Adjustable Batching Coding (ABC), was proposed by us, which uses redundancy coding to overcome random loss and uses retransmissions and window size shrink to relieve congestion. The stratified congestion control strategy makes the ABC scheme especially suitable for big data transmissions. However, there is no simulation platform built so far that can accurately test the performance of the network coding based transport protocols. We have built a modular, easy-to-customize simulation system based on an event-based programming method, which can simulate the ABC-based MPMH transport layer behaviors. Using the proposed simulator, the optimal parameters of the protocol can be fine-tuned, and the performance is superior to other transport layer protocols under the same settings. Furthermore, the proposed simulation methodology can be easily extended to other variants of MPMH communication systems by adjusting the ABC parameters.

1. Introduction

Big data applications have attracted many attentions. They have the four ‘Vs’ property, i.e., volume, velocity, variety, and veracity. The high volume requires high-throughput transmission links, and high velocity needs low end-to-end delay in the entire routing path. The variety implies different data types and veracity means that the data may be noisy or incomplete. If we use a wireless network to deliver the big data, it needs to provide high capacity for large amount of data transfer with high end-to-end reliability and also support various data types / priorities. Multipath transmission is a good choice to satisfy all these properties.

In many wireless-network-based applications, such as environmental monitoring [1] and tele-healthcare [2], the communication nodes typically have high density and there could be multiple nodes available for each hop to forward data.

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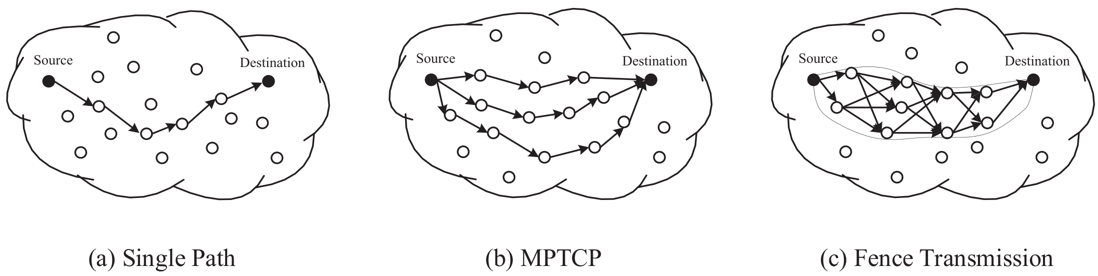

Fig. 1. Wireless networks with different routing topology.

However, general wireless routing protocols choose only one relay node for each hop, and cascade multiple hops to build a path from the source to the destination, as shown in Fig. 1(a).

In Fig. 1(a), the neighbors of the communication path might be idle and can thus help to forward data. If only one path is built, the communication capacities of those nodes are wasted. Thus, it is a natural idea to explore all the available nodes to forward data cooperatively. The traditional single-path routing may be widened as a multi-path topology, which significantly improves the throughput. From the transport layer's perspective, one of the most popular multi-path transport protocols is multi-path TCP (MPTCP), which has been standardized by Internet Engineering Task Force (IETF) in 2013 [3]. Each path independently transmits data assigned by the source node, and all paths cooperatively share the transmission task, as shown in Fig. 1(b).

Recently, the directional antenna technologies have been used to enhance the communication link quality by delivering data to a specific direction. Particularly, the multi-beam smart antennas (MBSAs) have been extensively used due to its concurrent, multi-directional communication capacity [4–6]. A MBSA with g beams can independently communicate with g nodes at the same time. The MBSA is an effective approach to deliver high-volume big data. If the wireless big data network is composed of nodes equipped with MBSAs, it is profitable to adopt multi-path topology to explore the multi-beam data transmission features of MBSAs. Although MPTCP builds multiple paths from the source to the destination, these paths work independently. Therefore, most nodes still work in a single-input, single-output mode except the source and destination node, which means that the multi-beam communication capacities of the intermediate nodes are wasted. To solve this problem, our previous work proposed a novel multi-path topology, namely fence routing, for which both the communication terminals and relay nodes work in a multi-input, multi-output mode, as shown in Fig. 1(c) [7].

Fence routing provides high throughput for wireless communications, and is a natural choice for big data transmissions. However, the transport control for such a routing scheme is very challenging. One of the issues is that in the communication pipe, the transmission quality varies from link to link, even from beam to beam. Some packets may confront congested queues at some nodes, resulting in arriving at the destination extremely late, which significantly increases the end-to-end delay of the entire path. For the big data applications with strict limitation on the end-to-end delay [8], we need to schedule the multi-beam transmissions between hops very carefully. For the TCP-based transport control protocols, if a packet is lost, the destination sends back a Negative ACK (NACK). For fence routing topology, since the source has no way to know which nodes are congested upon a NACK message, it has to slow down the sending rate for the entire fence pipe, which significantly decreases the throughput. Furthermore, in wireless communications, packet loss may be caused by various reasons in addition to network congestion, such as node mobility, burst interference, hidden terminal, etc. [9]. Apparently, for the packet loss caused by random link errors, reducing window size and slowing down the data rate may not be necessary [10,11].

Compared to the conservative, TCP-based transport control scheme, another design extremity is the rateless-code-based transport protocol, which keeps sending the encoded packets until a positive ACK is received by the source node [12–15]. The use of the rateless code to provide reliability avoids retransmission, and is effective to resist random loss. However, the rateless-code-based transport protocols do not have effective congestion healing measures. When the queues of some nodes are too full and begin to drop packets, sending more encoded packets may aggravate congestion. From this point of view, the rateless-code-based transport protocols are too *aggressive* when relieving congestions.

To overcome the above issues, a novel transport control method using Adjustable Batching Coding (ABC) was proposed in our previous work [16], which uses redundancy coding to resist random loss and uses retransmission to resist congestion. To evaluate the performances of the new transport control scheme, a comprehensive simulation system with flexible parameter setup is necessary. However, building such a network simulator is challenging. First, neither TCP nor the rateless coding oriented simulators can be used. Second, the MBSA has concurrent packet transmission/reception (CPT/CPR) constraint. Thus, a Rx/Tx synchronization scheme must be implemented in the simulator. Finally, the ABC coding algorithms, batch size adjustment, retransmissions, and other transport control features must be implemented as well.

Currently many network communication schemes are simulated via the Network Simulator version 2 (ns-2) or ns-3. For instance, a wireless sensor network is designed in ns-2 in [17]. Xu et al. [18] proposed a multipath data transfer model for heterogeneous wireless networks, and simulated the model via ns-2. Sun et al. [19] used ns-2 to analyze the routing performance of the wireless multipath networks. However, the relay nodes in these models are equipped with general directional