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Experimental Performance Study of Multipath TCP Over Heterogeneous Wireless Networks

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***Abstract*—Multipath TCP (MPTCP) enables a single TCP connection to use multiple paths for data delivery. This is expected to increase the overall data transfer throughput by utilizing the multihoming capabilities of communicating nodes. This paper introduces an experimental study of MPTCP connections of multihomed wireless nodes. The nodes' transceivers use two wireless interfaces. One is connected to a WiFi network, whereas the other emulates a dedicated link (such as a 3G or 4G). The performance of MPTCP is investigated in a practical setting, where the WiFi network suffers from interference of other nearby WiFi networks. The effect of connection parameters (such as maximum segment size and receiver buffer size) is examined. For such multihomed connections, our findings demonstrate that the MPTCP coupled congestion control algorithm can transfer more traffic over the WiFi link than the dedicated link only if the WiFi channel rate far exceeds the dedicated link rate.**

Keywords – **Multipath TCP, multihoming, heterogenous wireless networks, congestion control.**

I. Introduction

Currently, the wide deployment of wireless networks is very influential to human life. A multitude of applications rely heavily on wireless networks starting from normal voice conversation to social networking ending with machine-to-machine (M2M) communications and Internet-of-Things (IoT). Therefore, the demand on wireless bandwidth is steeply increasing in order to keep up with the tremendous increase of the number of wireless networking-based applications. On the other hand, the natural co-existence of different types of wireless networks (e.g., WiFi, 3G, and 4G) with an overlapped coverage generated a heterogeneous wireless medium. As a result, the popularity of multi-interface (referred hereafter as multihomed) wireless devices has lead to a new research focus on the usage of the resources of heterogeneous wireless networks to meet the current huge demand for wireless bandwidth [1].

Recent studies show that an incredibly large portion of data traffic passing through the Internet relies on the usage of the transmission control protocol (TCP) [2]. Moreover, future applications of M2M networks and IoT require reliable transmission of a large volume of data, which mandates employing the TCP protocol. However, the current available TCP protocol is designed to run over a single path not over heterogeneous wireless networks. This leads to a significant throughput degradation due to different delays and congestion parameters associated with each one of these networks. Multipath TCP (MPTCP) is a TCP variant recently provided by the Internet Engineering Task Force for multipath connections as an alternative to TCP [3]. MPTCP is able to dedicate a TCP sub-flow to each working interface of a multihomed device. However, the TCP protocol design fundamentally addresses wireline networks not wireless ones. TCP (and in turn MPTCP) connections over a wireless network often suffer from throughput degradation, specially when a significant amount of interference affects this network.

In this paper, we experimentally investigate the performance of the MPTCP protocol over heterogeneous wireless networks. We address a scenario where a number of multihomed wireless devices, each equipped with two wireless transceivers, concurrently share some data volume with one another. Each wireless device is connected to two different wireless networks. One network is a contention-based WiFi network that runs IEEE 802.11 protocol. The other network offers dedicated contention-free links to transmitters and receivers (such as 3G or 4G networks). The contributions of this paper are two-fold. First, we experimentally measure the overall throughput of a multihomed connection when varying essential MPTCP parameters such as the maximum segment size (MSS), the receiver buffer size, and the dedicated link capacity. The measurements are performed in a practical wireless channel setting, where nearby WiFi networks are operating during all the experiments. The effect of varying each parameter on the traffic share of the WiFi network and the dedicated link is observed. Second, we compare the MPTCP performance for the same setting but with different WiFi standards such as IEEE 802.11g/n operating in the 2.4 GHz band and IEEE 802.11a operating in the 5 GHz band. Although IEEE 802.11g/a are relatively old standards, the throughput performance of the new standards such as IEEE 802.11n and IEEE 802.11ac over long distances in indoor environments approaches the performance of IEEE 802.11g/a standards over short distances [4] [5]. Therefore, we use the IEEE802.11a/g as an emulation to the long distance indoor performance of the new standards inside the lab environment.

II. Related Works

Since the advent of Multipath TCP, it has sparkled the interest of many researchers [2], [3], [6]–[9]. In fact, a multitude of research works focus on the design and the implementation of MPTCP such as [6]–[8]. However, very few research works investigate the performance of MPTCP with multihomed wireless connections. The authors in [9] introduce an experimental study for the performance of an MPTCP connection established by a multihomed host connected to a server using a WiFi and a 3G connection. However, the server side is connected to the host through the Internet via a wired Ethernet network. Also, the data transfer time, RTT, and packet loss are the only parameters observed in [9]. Chen et al. propose an energy-ware MPTCP content delivery scheme for heterogeneous wireless networks. However, their research work relies on ns-3 simulations and mainly focuses on energy consumption [2].

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III. System Model

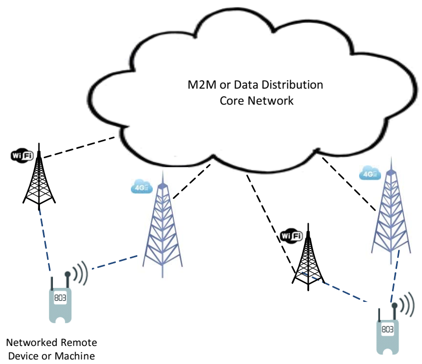


Fig. 1. The system model illustration.

We are interested in a scenario where a number of multi-homed wireless nodes share some information with one another concurrently. This scenario is motivated by the increasing demand of exchanging sensed data between remote machines or devices either using private M2M networks or via the Internet. The exchanged data can be processed further in order to extract some phenomena or to come up with distributed control actions or decisions.

In this scenario, each multihomed wireless node is equipped with two wireless transceivers. Each transceiver is connected to a different wireless network. The two wireless networks overlap in coverage and both of them are infrastructure-based networks. Each wireless transceiver is connected to a central connection point (e.g., a base station or access point) via single hop communication as illustrated in Fig. 1. One wireless network is a single-channel contention-based network following the WiFi IEEE 802.11 MAC protocol. The other one provides a contention-free channel access such as 3G or 4G networks.

Each multihomed node acts as a sender or a receiver. The senders and receivers are not connected to the same base station or access point as they are assumed to be located in different places. MPTCP is used at the sender nodes to transfer a data chunk to the receiver nodes. The MPTCP is assumed to use *Coupled* congestion control algorithm. This algorithm tries to balance the traffic load between different MPTCP sub-flows by pushing more data to the less congested sub-flow.

IV. Experimental Setup

The experimental setup mimics the system model via an emulated lab scenario. Each experiment is conducted in a practical setting and repeated at least 50 times. The WiFi networks used in the experiment suffer from significant nearby interference caused mainly by many IEEE 802.11n access points operating in the common non-overlapping channels of the 2.4 GHz band. Some amount of interference is also observed in the 5 GHz band, particularly on Channel 36 and Channel 48. Fig. 2 shows the experimental setup. Eight nodes are used to create four sender-receiver pairs. Every node has two interfaces; each is connected to a different network. One interface is connected to the WiFi network, whereas the other is a contention-free dedicated link that directly connects the sender to the receiver. The dedicated link emulates a cellular network connection, where we abstract the details of the core network assuming it provides low latency with much larger capacity compared to the wireless part. The WiFi interfaces of the sender nodes are connected to Wireless Router 1 and that of the receiver nodes are connected to Wireless Router 2. The second interface of sender nodes are configured as a software access point in order to create a dedicated link with the corresponding receiver nodes. This setup covers an area where each node is located at a minimum distance of 5m from the other node belonging to the same pair. In the following, we provide a detailed description for the experimental setup.

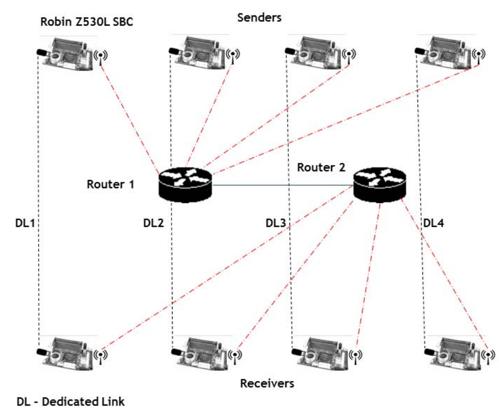


Fig. 2. The experimental setup.

Three main types of hardware equipment are used, namely, computing nodes, wireless routers, and wireless adapters. The computing nodes are fully functional single board computers (SBCs) in a small form factor. Our SBC is Toradex Robin Z530L, which is powered by an Intel Atom Z530 processor running at 1.6 GHz clock speed with 1 Gbytes of memory. In order to make Robin Z530L a dual-homed wireless node, we connect it to two wireless adapters, namely, Dell 1450 to emulate the dedicated link, and ASUS N53 or ThinkPenguin for WiFi connectivity. Two ASUS RT-N66U wireless routers are used to implement Router 1 and Router 2 in Fig. 2. The routers are re-flashed to Tomato firmware. Ubuntu Linux server version is installed on all the nodes. We use the default Linux kernel implementation of MPTCP, which adopts the coupled congestion control algorithm.

V. Experimental Results

In this section, the results of our extensive experimentation is introduced. Note that the experimental results in the following subsections are obtained with no maximum rate limitation applied to the WiFi routers. The dedicated link rate is limited to 6 Mb/s unless otherwise is mentioned. The throughput is measured by the time required to transfer a 15 MB file simultaneously between the four sender-receiver pairs.

A. MPTCP Throughput for Single-Interface and Multihoming

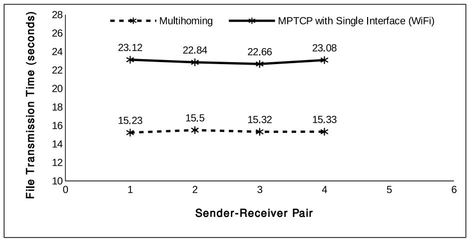


Fig. 3. File transfer time for single interface vs multihoming.

Fig. 3 shows the MPTCP file transfer time for different sender-receiver pairs using only a single WiFi IEEE 802.11n interface compared with multihomed MPCTCP throughput. As Fig. 3 reveals, the 15 MB transfered file takes on average around 23 seconds to be transferred over a single-interface connection, which is around 50% more than the time a multihomed connection takes (around 15 seconds on average). Apparently, the 6 Mb/s dedicated like is a valuable resource to the MPTCP protocol since the WiFi network suffers from nearby interference. The figure also indicates that the MPTCP acts fairly among all sender-receiver pairs since they perfrom almost similarly with small throughput differences mainly due to wireless channel impairments.

B. Dedicated Link Data Rate

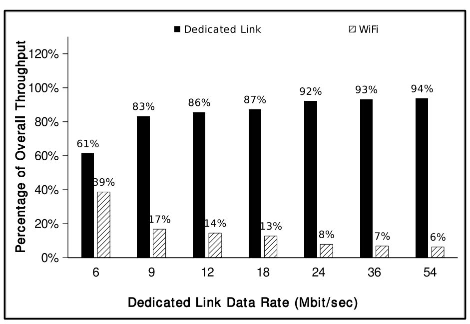


Fig. 4. Throughput performance with different dedicated link data rates.

Fig. 4 demonstrates the per node MPTCP throughput share of the WiFi IEEE 802.11g network and the dedicated link for different dedicated link data rates. As Fig. 4 reveals, the WiFi throughput share decreases dramatically with increasing the dedicated link rate. Moreover, the WiFi link is able to achieve the highest percentage (39%) of the overall throughput at a dedicated link speed of 6 Mb/s. The MPTCP sends most of the traffic over the dedicated link when the speed of this link reaches 54 Mb/s. Admittedly, channel sharing, packet collisions, and the interference from nearby networks contribute to decreasing the throughput of the MPTCP WiFi sub-flow.

C. Receiver Buffer Size

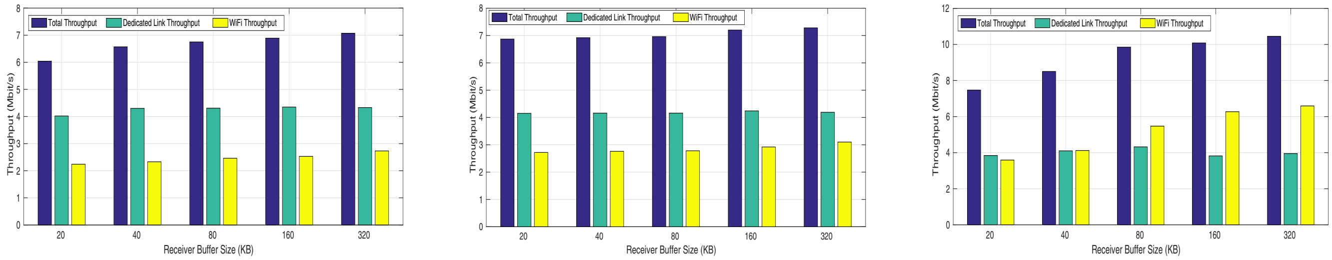
Fig. 5 presents the overall throughput for the multihomed connection with different values of receiver buffer size. Indeed, the receiver buffer size determines the maximum congestion window size that the MPTCP sender is allowed to use for data transfer. Moreover, the figure depicts the amount of throughput contributed by the WiFi interface and a 6 Mb/s dedicated link interface for different WiFi standards, namely, IEEE 802.11a, IEEE 802.11g, and IEEE 802.11n.

Figures 5(a) and 5(b) reveal that the MPTCP coupled congestion control algorithm generally prefers the dedicate link interface over the WiFi interface operating either in 2.4 GHz or in 5 GHz band with a maximum rate of 54 Mb/s irrespective of the receiver buffer size value. Increasing the receiver buffer size up to the default maximum value of 320 KB (as imposed by the Linux kernel) leads only to a slight increase of the MPTCP overall throughput compared with a buffer size of 20 KB. Similar observations can be noticed for the throughput share of the dedicated link and the WiFi network. However, the WiFi throughput share is slightly higher for IEEE 802.11a since it suffers less interference than IEEE 802.11g. Apparently, packet collisions due to contention-based channel sharing between the WiFi interfaces of the sending nodes (and nearby WiFi networks) play a major role in decreasing the WiFi throughput share. For different buffer sizes, throughput values below 3 Mb/s are achieved for the WiFi interface although the maximum data rate for IEEE 802.11a/g is 54 Mb/s shared between 4 nodes.

On contrary, Fig. 5(c) shows a significant improvement of the WiFi share when IEEE 802.11n is used for relatively large receiver buffer sizes. At relatively low maximum congestion window size (receiver buffer sizes of 20 and 40 KB) the throughput share of the WiFi and dedicated link is almost the same. However, by increasing the receiver buffer size, the MPTCP tends to transfer more data traffic over the IEEE 802.11n WiFi network than on the dedicated link making the overall throughput per sending node around 10.5 Mb/s. However, the WiFi share does not exceed 70% although the difference between the dedicated link rate and supported channel rates in IEEE 802.11n [10] is large.

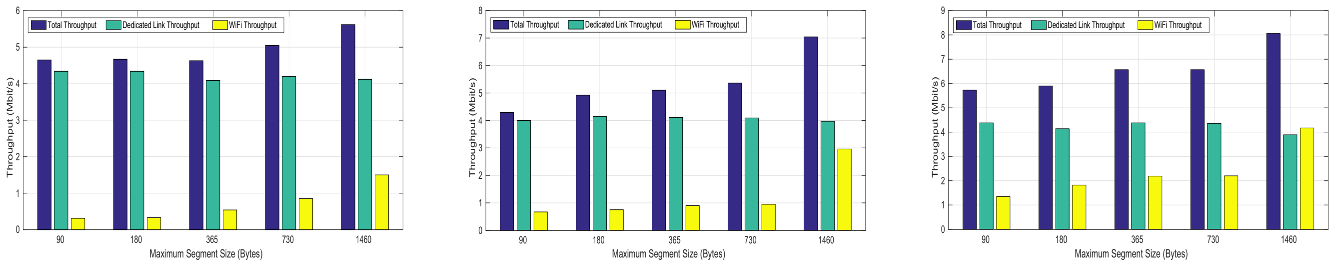
D. Maximum Segment Size

Fig. 6 depicts the MPTCP overall throughput performance per node including the throughput for each interface versus different MSS values. It is observed that increasing the MSS value leads to an increase in the amount of data traffic sent over the WiFi link, whereas the traffic share of the dedicated link is not significantly affected. The reason is that the number of transmitted packets decreases with increasing the MSS (since the file size is fixed). This, in turn, reduces the chance of packet collisions leading to a better overall throughput. A comparison between Fig. 6(b) and Fig. 6(a) reveals that the throughput share of IEEE 802.11a interface outperforms IEEE 802.11g due to less interference effect on the 5 GHz band from the nearby networks. For IEEE 802.11n, Fig. 6(c) shows that increasing the MSS value boosts the WiFi share to become slightly more than the dedicated link share.



(a) Throughput performance for IEEE 802.11g. (b) Throughput performance for IEEE 802.11a. (c) Throughput performance for IEEE 802.11n.

Fig. 5. MPTCP Throughput performance for different WiFi standards with different receiver buffer sizes.



(a) Throughput vs MSS for IEEE 802.11g. (b) Throughput vs MSS for IEEE 802.11a. (c) Throughput vs MSS for IEEE 802.11n.

Fig. 6. MPTCP Throughput performance for different WiFi standards with different MSS values.

E. Discussion

Our experimental results indicate that an MPTCP multihomed connection, which consists of a WiFi interface and a dedicated link interface, outperforms a single WiFi connection. Although this is expected, a multihomed connection generally costs more than a single WiFi connection. Dedicated links such as 3G or 4G links often come with a per-usage price plan form their service providers. This implies that the MPTCP multihomed connection can be made cost effective by increasing the share of the WiFi link. Our study shows that using the maximum MSS and a high receiver buffer size enhance the WiFi share. However, the MPTCP coupled congestion control algorithm prefers the WiFi network only when the available WiFi rate is much higher than the available dedicated link rate.

VI. Conclusion

In this paper, we experimentally investigate the MPTCP throughput performance over heterogeneous wireless networks. The MPTCP coupled congestion control algorithm is studied using a multihomed connection that consists of a WiFi link and a dedicated link. Our experimental results show that the MPTCP coupled congestion control algorithm increases the WiFi traffic share as the maximum segment size or the receiver buffer size (maximum congestion window) increases. Furthermore, it is observed that the WiFi share of the MPTCP multihomed connection significantly decreases with increasing the capacity of the dedicated link. Our experiments reveal that the WiFi share can exceed the dedicated link share only if the WiFi data rate is far higher than the available rate of the dedicated link.

VII. Acknowledgments

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