A Traffic Burstiness-based Offload Scheme for Energy Efficiency Deliveries in Heterogeneous Wireless Networks

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***Abstract*—Latest mobile multimedia applications have important impact on smartphone usage in terms of both energy consumption and Quality of Service (QoS) levels. This impact is dependent on the level of burstiness of the multimedia traffic. This paper proposes eMTCP-BT, a novel energy-efficiency-oriented offloading scheme for multipath TCP (MPTCP) deliveries which considers traffic burstiness level in its decision making process. Mobile applications traffic is categorized according to its burstiness level, including some most widely-used services such as Voice over IP (VoIP) service, video streaming, large file downloading and web browsing. eMTCP-BT increases the energy efficiency of the multipath TCP content deliveries by performing an innovative distribution of the overall traffic for its delivery via the available wireless network interfaces (and paths) based on the traffic burstiness level. Real traffic trace-based simulation experiments have been conducted involving a mobile device receiving traffic over the Long Term Evolution (LTE) and IEEE 802.11 interfaces. Result analysis demonstrates how eMTCP-BT outperforms both eMTCP and the original MPTCP in terms of energy efficiency by up to 91.68%.**

***Index Terms*—traffic pattern; Multipath TCP; traffic offloading; energy efficiency, burst**

I. INTRODUCTION

There is a significant growth in rich media applications delivered to mobile devices which have diverse traffic-related characteristics [1]. Among these applications, video streaming and voice over IP (VoIP) services are sensitive to both delay and jitter and in general require high bandwidth. Web browsing and data transportation services, on the other hand, have low bandwidth requirements. Additionally, the bursty nature of IP traffic may affect the energy consumption of mobile devices. For instance, the wireless network interfaces deployed on mobile devices are active whenever there are packet transmissions and idle if the transmission stops. The unpredictable arrival time of IP packets causes the interfaces to switch frequently from active to idle states, resulting in energy waste. Mobile devices might simultaneously operate one or more multimedia applications as shown in Fig.1. In this context, it is important for the mobile devices to categorize multimedia applications according to their types and burstiness levels and accordingly apply best mechanisms to save energy.

With the application layer protocols providing primitive functionality for wireless mobile applications, the transport layer protocols underneath handle communication support. The classic TCP protocol has been widely used as one of the most common transport layer protocols. Recently the IETF

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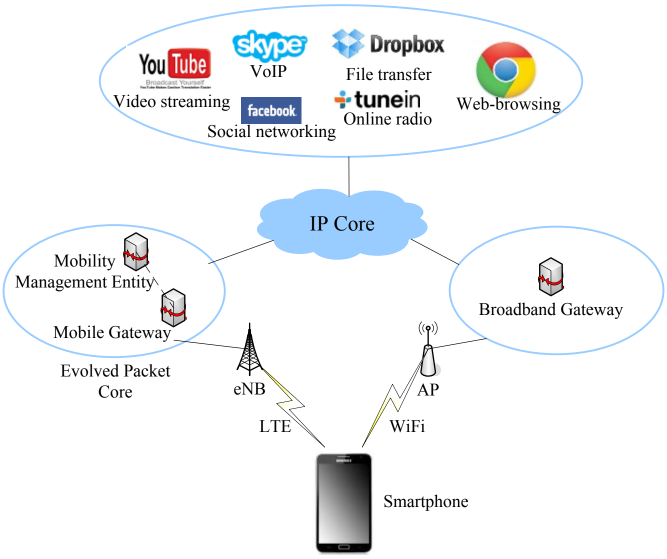

Fig.1. Smartphone applications with different traffic pattern

Multipath TCP (MPTCP) protocol [2][3] addresses some performance limitations of TCP in wireless environments in terms of both throughput and delay support. With MPTCP, more than one wireless interfaces on the mobile device are active at the same time to handle data transmissions, so that the application throughputs are significantly improved. However, MPTCP achieves higher throughput at the cost of consuming extra battery, which affects mobile user experience. To find a tradeoff between the improvement of the data transmission throughput and the total energy consumption of mobile devices, we proposed an energy-aware MPTCP-based solution named eMTCP [4]. eMTCP achieves energy saving by performing data traffic offloading, moving part of the data traffic from the most energy-consuming wireless interface to the others and maintains the multiple path transmission mechanism of MPTCP so that higher application service performance is also supported by increasing data transmission throughput.

Extending eMTCP, this paper proposes eMTCP-BT, a novel energy-efficiency-oriented traffic offload scheme which increases the energy efficiency multipath rich media applications by offloading traffic to low energy consumption interfaces based on traffic burstiness levels. Real trace-based simulations are performed and show how eMTCP-BT outperforms both MPTCP and eMTCP in terms of energy-efficiency when traffic with different burstiness levels is delivered to a mobile device. The mobile device in the simulations is designed to simultaneously receive traffic via the 3GPP [5] Long Term Evolution (LTE) [6] and IEEE 802.11 [7] interfaces.

The remainder of this paper is organized as follows. Section II presents related works on traffic offload and energy optimization solutions. Section III describes the principle and functionality of eMTCP-BT and defines the traffic burstiness level categorization. Section IV describes the simulation-based test bed settings and presents the relevant test results. The last section concludes the paper and presents future works.

II. RELATED WORKS

Recently, many solutions have been proposed in the area of mobile traffic offload and smartphone energy optimization.

A. Mobile Traffic Offloading

The explosion of mobile IP data traffic requires efficient offloading solutions [1] [8], which aim to increase both network operators' revenues and customers' quality of experience levels. For instance, operators can offload the traffic of high bandwidth applications such as video conferencing data from cellular networks to broadband networks, protecting the key business of their cellular service (e.g. voice communication) with no additional infrastructure investments.

3GPP has already released standards such as Local IP Access (LIPA) and Selected IP Traffic Offload (SIPTO) [9], to support basic traffic offload. For instance, mobile traffic based on LIPA and SIPTO is not necessarily delivered via mobile core cellular networks. However, advanced features to support like user equipment mobility are still under development. In [10], a mobile traffic offloading solution through opportunistic communications is proposed in order to reduce operational costs. A selected target set of users is specified to receive delay-sensitive multimedia services (e.g. video streaming, on-line music, etc.) via mobile networks. These target-users can then help to disseminate the information to the non-target users via opportunistic communications, which are realized via WiFi or Bluetooth. An extensive trace-driven simulation study has verified that mobile data traffic can be offloaded by up to 73.66%. In [11], the tradeoff between the amount of traffic offloaded and users' satisfaction was investigated. A novel incentive scheme was designed in which user traffic with high delay tolerance and large offloading potential is given higher priority during offloading. Comprehensive simulations validate the efficiency and robustness of the proposed framework. However, to the best of our knowledge, none of the mobile traffic offloading solutions considers the energy consumption at mobile devices for offloading multimedia traffic services.

B. Multimedia Traffic Characteristics-aware Mobile Energy Optimization

Recently, the impact of emerging mobile internet applications (e.g. VoIP, video streaming, web-browsing, social networking, etc.) on the energy consumption at mobile devices has attracted very much attention [12]. Multimedia traffic pattern (e.g. burstiness level) acts as a key factor in the device energy consumption and consequently in the effort for its optimization.

In [13], the distribution of internet packet inter-arrival time of smartphone traffic was studied and the results have indicated that the network traffic is mostly bursty. The Low Energy Data-packet Aggregation Scheme (LEDAS) was

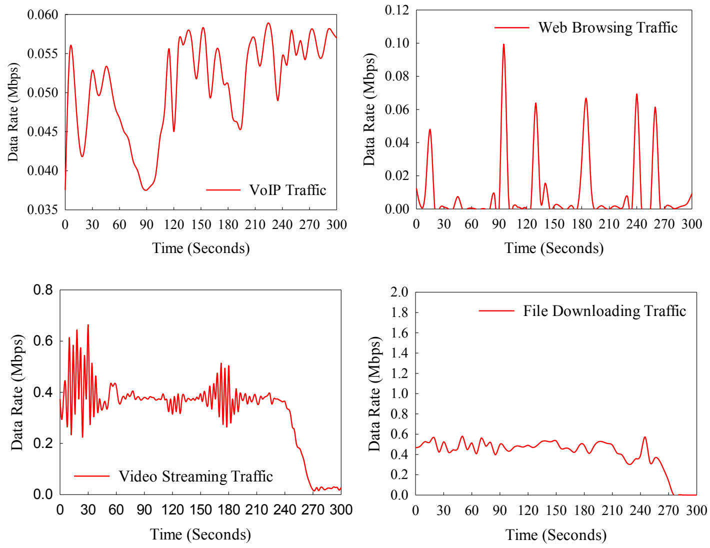

Fig.2. Traffic profiles for the different content types of application: a) VoIP; b) Web browsing; c) Video streaming; d) File Downloading

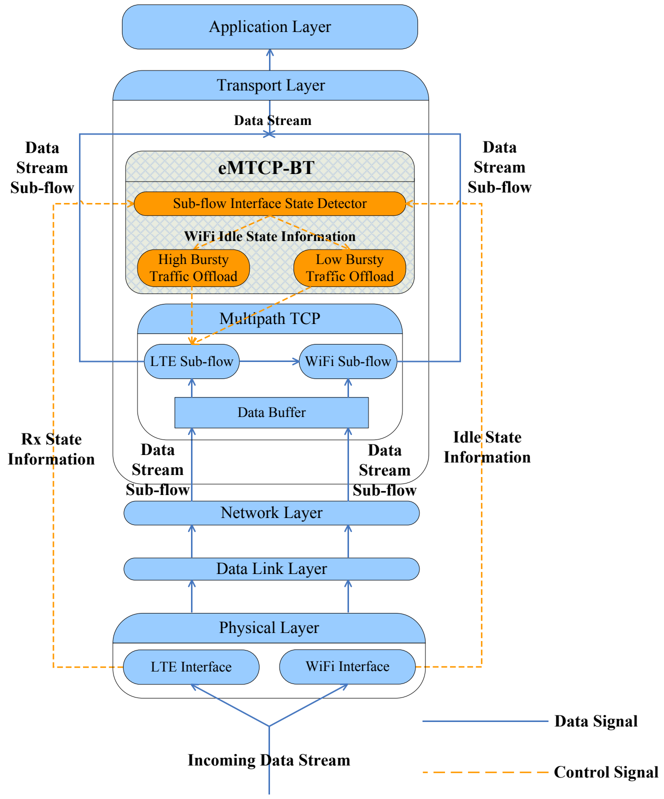

Fig.3. Architecture of eMTCP-BT deployed on smartphones

proposed which accumulates several upper layer packets into a burst at MAC layer. When using LEDAS, the radio interface is kept idle longer, saving energy at smartphones. Q-PASTE [14] is a cross-layer solution which enables MAC layer to achieve energy savings by adjusting data delivery based on application-layer traffic pattern. In [15], the energy consumption of smartphone Multimedia Cloud Computing (MCC) applications is studied. Extensive tests conducted demonstrate that MCC services have positive impact on smartphone energy savings. Specifically, uploading and downloading a video document by using HTTP and FTP via both 3G and WiFi is considered. Results show how MCC enables smartphone energy savings of up to 70%. A cross-layer smartphone battery and stream-aware adaptive multimedia delivery mechanism (BaSe-AMy) was designed in [16]. The solution monitors mobile device remaining battery, remaining video stream duration and packet loss rate. Based on these values, a video quality adaptation module is proposed to achieve power savings. Experimental results show how BaSe-AMy increases the battery life with up to 18%.

Unfortunately, none of the research works mentioned considers multimedia traffic characteristics when optimizing smartphone energy consumption in conjunction with mobile traffic offloading.

III. eMTCP-BT Principle

A. *Basic Functionality of eMTCP*

eMTCP-BT makes use of the information on traffic burstiness level and enhances the functionality of eMTCP in order to improve the energy-efficient multipath traffic distribution.

The basic goal of the previously proposed eMTCP scheme is to provide support for traffic offload from the more energy-consuming interface to a less consuming one, without affecting much the QoS level of applications. When application traffic is coming from a remote server to the local mobile device, the data is stored in the TCP receiver buffer before it is sent to the upper layers. During this process, eMTCP monitors the communication channels (e.g. LTE and WiFi) to check whether they are either *idle* or receiving data (*Rx*). Whenever a channel with higher energy consumption receives data and another channel with lower energy consumption is *idle*, eMTCP offloads the data queued in the TCP receiver buffer from the first sub-flow to the second sub-flow. This results in saved energy at the device.

eMTCP enables multipath application traffic delivery at higher data rate as multiple wireless interfaces are used simultaneously for transmission and lower energy consumption than other multipath solutions as traffic offload is performed when possible from the interface with highest energy consumption (e.g. LTE) to another one (e.g. WiFi).

B. *Traffic Burstinesst Level Categorization*

One of the typical patterns used for distinguishing different types of application traffic is the burstiness level (i.e., the degree of fluctuation in the traffic data rate). In this paper we categorize the applications, based on their burstiness levels, into two classes: high bursty and low bursty. The high bursty traffic data rate varies significantly throughout the transmission. The low bursty traffic data rate fluctuates very little during data exchange. However, both application type and protocols being used influence traffic burstiness.

In this paper, TCP traffic is considered only and each of the two above-mentioned traffic burstiness classes has associated two different application types, respectively. High bursty traffic class includes the following application traffics:

- *VoIP*: data rate varies a lot but in general is low in comparison with the background.
- *Web browsing*: data rate fluctuates much, but in general is higher in comparison with VoIP.

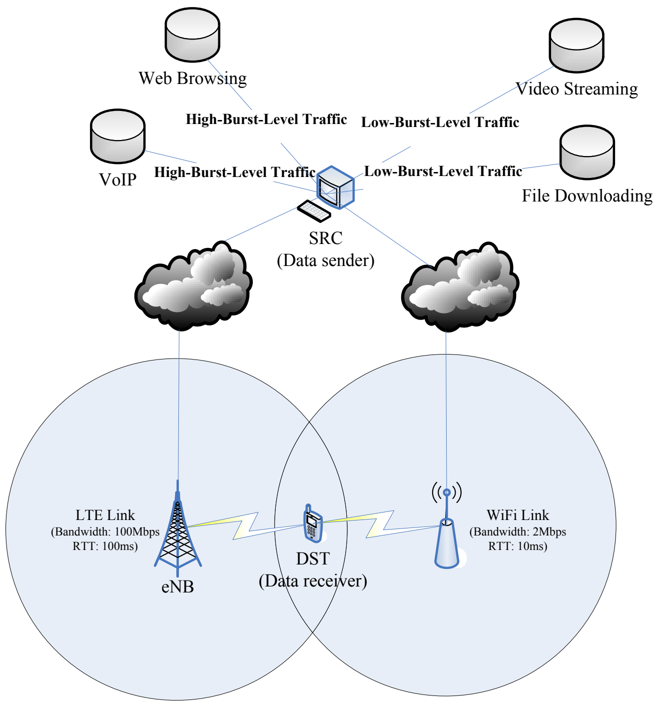

Fig.4. Network topology used in application traffic simulations

Algorithm I
Algorithm for eMTCP-BT Offload between LTE and WiFi

Determine X_h as the optimal offload percentage for high bursty traffic
Determine X_l as the optimal offload percentage for low bursty traffic;
Determine X_m as the optimal offload percentage for mixed bursty traffic;
while (1) {
Compute BL_X - the burstiness level of current traffic;
if (*Rx* is detected in LTE sub-flow) {
if (WiFi channel is idle) {
if (WiFi channel not congested) {
Switch (*BLx*) {
case “high bursty”:
Offload X_h % data from LTE to WiFi;
break;
case “low bursty”:
Offload X_l % data from LTE to WiFi;
break;
case “mixed bursty”:
Offload X_m % data from LTE to WiFi;
break;
}
}
else
if (LTE channel congested)
{
Perform congestion control;
}
}
}
}

The low bursty traffic class includes the following application traffics:

- *Video streaming*: relative constant on long term, but may experience short-term fluctuations.
- *File downloading*: except transitory periods, it is low bursty traffic.

General traffic patterns for these four applications are shown in Fig.2 a) b) c) and d).

C. *Proposed eMTCP-BT principle*

The block architecture of the proposed eMTCP-BT scheme, when considering a LTE and WiFi-based network environment, is illustrated in Fig. 3. The scheme is deployed at the upper transport layer, detecting the situation of the application traffic flow which contains multiple sub-flows, the number of which depends on the number of interfaces used. In Fig. 3 the application traffic flow is separated into two sub-flows: LTE and WiFi sub-flows. The application traffic flow is a mixture of more than one isolated data streams with different burstiness levels.

The principle of eMTCP-BT is described in Algorithm I. Similar to eMTCP, eMTCP-BT detects the channel states of the LTE and WiFi sub-flows and uses the MPTCP congestion control mechanism to check if either of the sub-flow is congested. When the WiFi channel is idle and not congested, the mixed traffic from multiple applications is offloaded to it to save energy for the device. However, if the WiFi channel is congested in this case, transmission continues through the LTE interface to maintain basic QoS level. If both channels are congested, then the transmission is interrupted and the congestion control mechanism is triggered. Based on this mechanism, for incoming application traffic with different burstiness levels (high bursty, low bursty or a mix), eMTCP-BT calculates the energy efficiency it could obtain by using different traffic offload percentages from 0% to 100%. It then determines the percentage for which the highest energy efficiency is achieved as the optimal offload percentage for the current bursty application type and uses this value.

IV. Simulation-Based Testing and Result Analysis

This section presents the detailed settings for the simulation-based testing experiments. Modeling and simulations were performed using Network Simulator 3 (NS-3) version 15 [17]. The performance of eMTCP-BT was assessed for application traffic with high and low burstiness level in comparison with MPTCP and eMTCP in terms of **energy efficiency**, which is defined as the **ratio** between the **data transmission throughput** and the **energy consumption** in the same period.

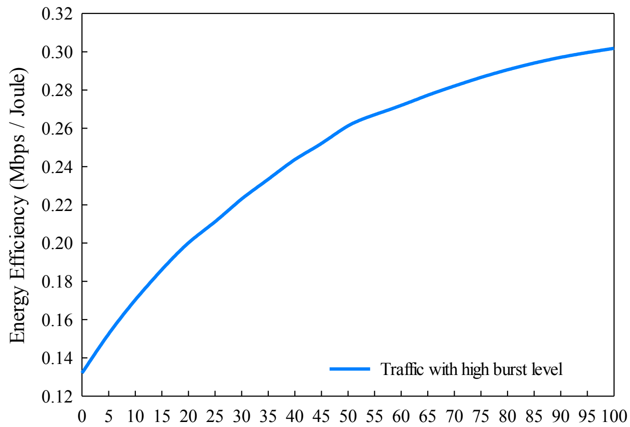

Fig.5. Change of average energy efficiency according to the change of offloading amount for high-burst-level traffic

TABLE I
DETAILS OF SIMULATION PARAMETERS

Application Type	VoIP	Web Browsing	Video Streaming	File Downloading
Traffic Description	5-min Skype voice session	5-min surfing the Internet webpages	5-min online video clip playing on YouTube	5-min downloading large file from remote server via HTTP
Traffic Burst Level	High		Low	
Average Data Rate (Mbps)	0.06	0.01	2	1
Average Packet Size (Bytes)	150	600	1460	1540
Traffic Duration (s)	300	300	300	300
Distance between data sender and receiver (m)	60	60	60	60
Initial Battery capacity (Joule)	300	300	300	300

A. *Simulation Test-bed Setup*

The network topology used in our experiments is presented in Fig. 4, which involves three wireless nodes: one used as the remote data source (referred to as SRC), another used as the data sink (referred to as DST) which represents the mobile device and the last one as the eNB node in the LTE network. The position of the DST node is within the signal coverage of both the LTE and WiFi networks, so that both LTE and WiFi interfaces on the local wireless mobile device could be enabled simultaneously.

We use the four types of application traffic mentioned in Section III B as traffic input for testing. In the simulation the application traffic is generated from packet trace files which are captured with the Wireshark software [18] during real data delivery scenarios. The detailed parameters of the four application traffic types are listed in Table I together with those of the network topology.

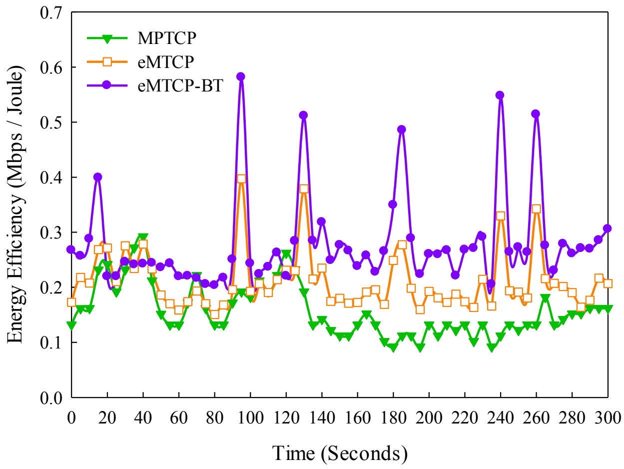

Fig.6. Energy efficiency of MPTCP, eMTCP and eMTCP-BT for high-burst-level traffic

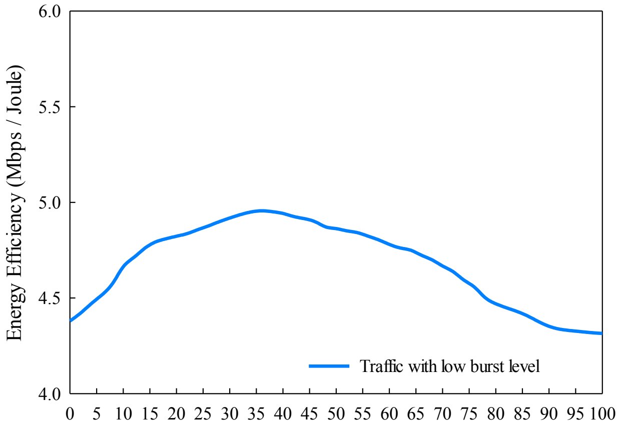

Fig.7. Change of average energy efficiency according to the change of offloading amount for low-burst-level traffic

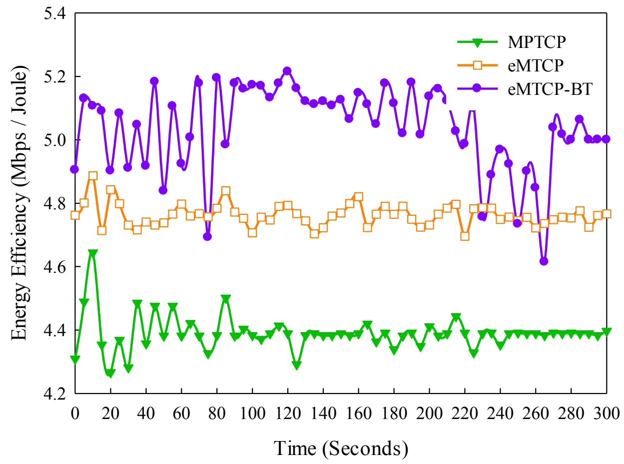

Fig.8. Energy efficiency of MPTCP, eMTCP and eMTCP-BT for low-burst-level traffic

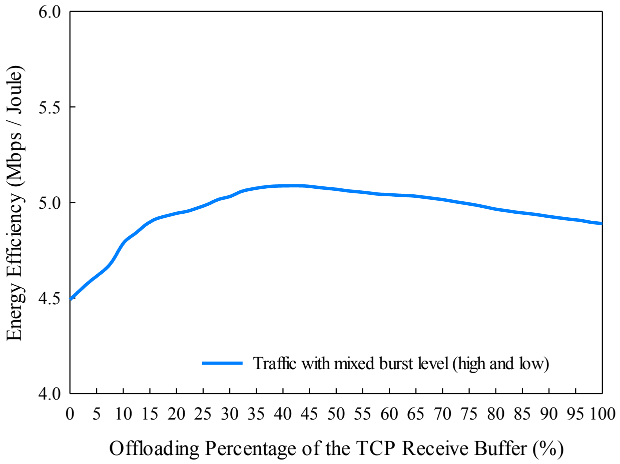

Fig.9. Change of average energy efficiency according to the change of offloading amount for mixed-burst-level traffic

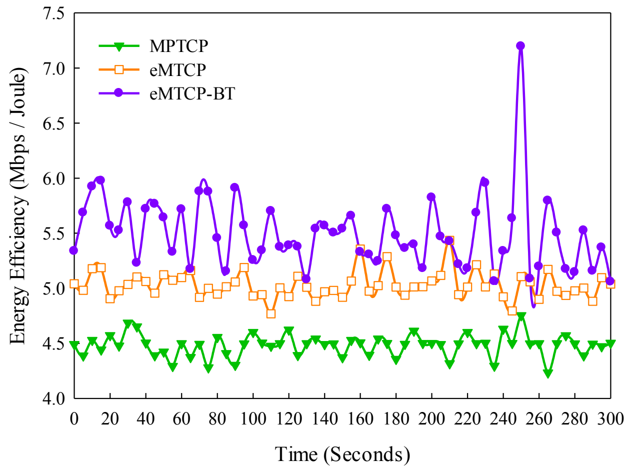

Fig.10. Energy efficiency of MPTCP, eMTCP and eMTCP-BT for mixed-burst-level traffic

B. Test Scenarios

The following three scenarios are designed for performance assessment in terms of energy efficiency of the traffic distribution between the LTE and WiFi channels:

- *Scenario 1*: uses 300-second high bursty traffic: VoIP and web browsing. The average bit rate is 60 Kbps for VoIP and 10 Kbps for web browsing. The average packet size is 150 bytes for VoIP and 600 bytes for web browsing.
- *Scenario 2*: makes use of 300-second low bursty traffic: video streaming and file downloading. The average bit rate is 2 Mbps for video streaming and 1 Mbps for file downloading. The average packet size is 1460 bytes and 1540 bytes, respectively.
- *Scenario 3*: contains 300-second traffic of all the four types already described in scenarios 1 and 2 and with the same settings.

In each of the three scenarios, the traffic performance measured in terms of energy efficiency is evaluated for MPTCP, eMTCP and eMTCP-BT as the transport layer protocols in turn.

C. Result Analysis

In the three test scenarios, the traffic offload percentage ranges between 0% and 100%. eMTCP uses a fixed offload percentage of 24% between LTE and WiFi regardless of traffic burstiness level, which is non-optimal in terms of energy efficiency, while eMTCP-BT determines the optimal percentage. MPTCP performs no traffic offload.

Fig. 5 shows how the energy efficiency increases when the traffic offload percentage increases from 0% (i.e. no traffic offload) to 100%. In this case, the employment of eMTCP-BT with the 100% optimal offload percentage in this scenario results in 91.68% and 15.95% improvement in energy efficiency in comparison with MPTCP and eMTCP, respectively, as shown in Fig. 6.

The same investigation is performed in the second scenario for the low bursty applications. Fig. 7 shows how the energy efficiency increases when the traffic offloaded from LTE to WiFi increases from 0% to approximately 36%. When the offload percentage grows from 36% to 100%, the energy efficiency decreases as the data size allocated to the WiFi link exceeds its capacity and causes overall traffic throughput reduction. As a result, in this scenario, the optimal traffic offload percentage from LTE to WiFi determined by eMTCP-BT is 36%. As shown in Fig. 8, in this case the energy

TABLE II
PERFORMANCE EVALUATION IN TERMS OF ENERGY EFFICIENCY FOR EMTCP-BT, EMTCP AND MPTCP

Scenario	**Scenario 1 – Traffic with high burstiness level**		**Scenario 2 – Traffic with low burstiness level**		**Scenario 3 – Traffic with mixed burstiness level**	
Transport-layer Protocol	**Average Energy Efficiency (Mbps/Joule)**	**Traffic Offload Percentage (%)**	**Average Energy Efficiency (Mbps/Joule)**	**Traffic Offload Percentage (%)**	**Average Energy Efficiency (Mbps/Joule)**	**Traffic Offload Percentage (%)**
MPTCP	0.1574	0	4.390	0	4.483	0
eMTCP	0.2104	24	4.763	24	5.031	24
eMTCP-BT	0.3018	100	5.038	36	5.499	42

efficiency of using eMTCP-BT is with 43.45% and 5.77% better than those of MPTCP and eMTCP, respectively.

The benefit of deploying eMTCP-BT in the third scenario is indicated in Fig. 10. The energy efficiency increases with 22.69% and 10.32% in comparison with MPTCP and eMTCP, respectively. Similar to the case in the second scenario, at approximately 42% of the data queued in the TCP receiver buffer, the energy efficiency reaches the maximum level, which is determined by eMTCP-BT. Moreover, as the high bursty traffic is mixed with the low bursty traffic, the optimal traffic offload percentage increases (as seen in in Fig. 9 in comparison with Fig. 7) due to the influence from the growing tendency of the optimal traffic offload percentage for the high bursty traffic.

The benefit in terms of energy efficiency in the three scenarios is concluded in Table II. It is obvious that applications with different burstiness level significantly affect the optimal traffic offload percentage. The results show clearly how significant energy saving is achieved with no negative effect in terms of quality of service (i.e. the throughput has not been affected) when eMTCP-BT determines the optimal traffic offload percentage.

V. CONCLUSION AND FUTURE WORK

This paper proposes eMTCP-BT, a novel energy-efficiency-oriented offload scheme for Multipath TCP (MPTCP) deliveries, which considers traffic burstiness levels in its decision making process. Simulation test results show how up to 91.68% and 43.45% energy efficiency improvement is achieved when traffic with high burstiness level is delivered using eMTCP-BT, in comparison with MPTCP and eMTCP, respectively. Lower but still significant benefits are obtained when low bursty and mixed traffic is carried.

Future work focuses on proposing a traffic-pattern-aware adaptive traffic offloading scheme for mobile devices, which dynamically adjusts the offload percentage to the value that achieves best energy efficiency according to the background traffic of the current application.

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