Buffering... energy for mobile devices: A “store and rendezvous” approach *

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Abstract. We exploit the traffic shaping potential of network storage and improve energy efficiency for mobile devices through the creation of idle communication intervals. We model the activity patterns between the wired/wireless gateway and the wireless battery-powered receiver, and employ a rendezvous mechanism that utilizes periods of inactivity created by the traffic shaping function of the network. In case multiple receivers are simultaneously active, a scheduling algorithm limits overlaps of buffer flushes. Our scenarios are based on the DTN paradigm, however, our approach is not DTN-specific. The presented simulation study involves three main types of Internet traffic (i.e. file transfer, streaming and web browsing) and demonstrates that our proposed scheme achieves significant energy conservation for mobile receivers involving, under most circumstances, only mild performance cost.

Keywords: Energy efficiency, 802.11, internetworking, DTN

1 Introduction

Mobile devices have become a powerful tool for communication, storage and entertainment, and often undergo several hours of daily use, which stretches their energy storing capabilities. They are equipped with increasingly more powerful CPUs, larger memory capacities, faster wireless network adapters, and a set of applications that require internetworking capabilities. However, advances in battery technology have not been able to match the increased energy demand. The main sources of energy expenditure have been identified in the various subsystems of a mobile device [1], namely: CPU, memory, display, audio and wireless networking. For applications that heavily rely on the networking subsystem, the related functions may account for as much as 60% of the total power necessary for the mobile device operation [2]. Consequently, improving the energy efficiency of the networking subsystem has drawn significant attention from the research community and has led to the implementation of energy-saving features in a number of wireless networking applications.

The ubiquitous 802.11 standard [3] confronts the energy efficiency problem by providing a power-save mechanism, which is, however, limited by the probabilistic nature of incoming data as well as the relatively small buffer space at the access point. This has led many researchers into looking for alternative methods, typically involving buffering at a “base station” rather than an “access point”, thus highlighting that the device operation extends in higher network layers.

Our solution to the energy efficiency problem demonstrates the potential of Delay/Disruption-Tolerant Networking (DTN) to shape internetwork traffic in a manner that allows mobile devices to balance their energy expenditure with minimal cost on throughput.

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We employ DTN in order to improve the energy efficiency of mobile devices in an infrastructure, wired-cum-wireless Internet setting with a last-hop 802.11 connection. The DTN functionality is extended with a rendezvous mechanism (first described here [4]) that allows mobile receivers to switch their Wireless Network Interface Cards (WNIC) to the sleep state during idle intervals.

In the current work, we study the operation of our DNT overlay for various types of Internet activity in terms of both the energy efficiency improvements for the mobile devices as well as possible deterioration of the user experience. Additionally, we explore alternative rendezvous scheduling aimed at minimizing transmission overlaps when multiple devices are active, further enhancing the device energy efficiency. In order to better interpret the simulation outcome we also provide a simple mathematical formulation of the buffering process.

The rest of the paper is organized as follows: In section 2 we present related work focusing on energy efficient networking and DTN. In section 3 we describe our proposed solution and provide a mathematical formulation of the buffering mechanism. In section 4 we present the experimental methodology and in section 5 the simulation results. Finally, in section 7 we summarize our conclusions and discuss future research plans.

2 Related Work

In [5] Jones et al. provide a comprehensive survey of energy-efficient protocols for wireless networks and summarize the design principles for achieving energy efficiency. At the lower network layers, such as the physical and data link/MAC, substantial effort in the energy efficiency research involves the WLAN standard 802.11[3]. The 802.11 protocol provides an energy-saving mechanism that buffers incoming data at the access point, allowing the mobile devices to temporarily switch their wireless interfaces to the sleep state. The energy conservation potential of 802.11 is limited by the relatively small buffer space at the access point and the lack of visibility at higher network layers, leading many researchers into examining alternative methods based on the same core principle.

In [6] Chandra and Vahdat highlight the limitations of the 802.11 PSM and propose an application-specific traffic shaping mechanism for multimedia streaming that can be implemented either on the server (source of the stream) or at the access point. In [7], Adams and Muntean propose an Adaptive-Buffer Power Save Mechanism (AB-PSM), again for multimedia streaming, which hides data from the BS and allows for longer idle intervals. Energy-saving strategies when streaming from a single server to multiple clients are explored by Acquaviva et al. in [8]. Zhu and Cao in [9] expand on the proxy idea by introducing a scheduler service at the base station and a proxy at the mobile terminal. Finally, in [10] the authors exploit windows of opportunities for optimal transmissions, while in [11] transmission behavior is adjusted according to network characteristics. Most of the described solutions target streaming applications and involve the installation of specialized components, such as proxies, schedulers and local services in order to operate. The network *per se* does not participate in the effort for energy efficiency.

The DTN computer networking architecture was designed to cope with long propagation delays and lack of continuous end-to-end connectivity. Despite its original conception as space-communications architecture, DTN has been proposed for applications in various settings, including wired or wired-cum-wireless networks on the edges of the well-connected Internet. The DakNet [12] network employs DTN to provide Internet connectivity by physically transferring data using appropriately equipped vehicles. Significant attention from the research community has also been drawn by DTN applications related to vehicular communications [13][14][15] and pocket-switched networks [16], which aim at providing Internet connectivity to commuters and mobile users respectively. More recently, DTN has been combined with resource pooling techniques that share private broadband connections in order to provide Less-than-Best-Effort, free Internet services to all users [17].

Our contribution lies in the use of the inherent capabilities of DTN for shaping internetwork traffic in a manner that allows mobile receivers to suspend their WNICs with minimal cost on throughput. In our previous work [18] we have extended the DTN functionality with a rendezvous mechanism employed between the base station and the receiving DTN nodes, for data transfers that originate on the Internet and target a mobile device on an 802.11 LAN. The performance of our solution was evaluated for a single active mobile receiver downloading a file. In this work we extend our study by quantifying the energy efficiency improvements achieved for the three main types of Internet traffic (i.e. file transfer, media streaming and web browsing) and assessing the impact of our solution on the user experience for each such traffic type. Furthermore, we propose alternative rendezvous mechanisms in case multiple mobile receivers are simultaneously active and evaluate the performance of these alternatives. In order to better grasp the potential and the limitations of our approach we also formulate the operation of the rendezvous mechanism in mathematical terms.

3 Energy-Efficient Internetworking Overlay

Our energy-efficient DTN overlay is deployed on a traditional internetworked wired-cum-wireless topology with a last-hop WLAN connection, aiming to improve energy efficiency for mobile devices. The proposed overlay exploits the inherent DTN capability for shaping internetwork traffic in a manner that allows mobile devices to balance their energy expenditure. A minimum deployment of the proposed energy-efficient DTN overlay involves employing DTN on three nodes: Source, Base Station (BS) and Mobile Receiver (MR). In our previous work [18], transmission scheduling from the BS to each MR was carried out independently of the transmissions to other MRs with active incoming flows. In this work, we extend the BS functionality so that transmission scheduling considers the incoming traffic for all active MRs, further improving the energy efficiency of the receivers.

3.1 Buffering Energy-Saving Potential

In order to assess the potential of the energy-efficient overlay as well as identify the practical limitations of the proposed solution, we developed a mathematical formulation describing the energy-saving potential of the buffering mechanism. Due to space scarcity we include an abbreviated description of the formulation; a detailed derivation of the formulation can be found here [19]. The formulation is based on the following simplifying assumptions: The incoming and outgoing data rates at the BS is constant, wireless traffic is one-way from BS to MR, and the data to be transferred is of a certain predefined amount.

The diagram of Fig. 1 depicts an example scenario where the output rate (OutRate) is double the incoming rate (InRate) and the transfer size (Size) is three times the buffering size (Buffer). The WNIC is assumed to be initially active and immediately switched to the sleep state, allowing for the buffer at the BS to fill (i.e. for a time period of Buffer/InRate). The WNIC must commence the switch to the active state at a time equal to the transition time between the idle and active states (TransTime) prior to the rendezvous time, so that it will be fully operational when the BS starts transmitting.

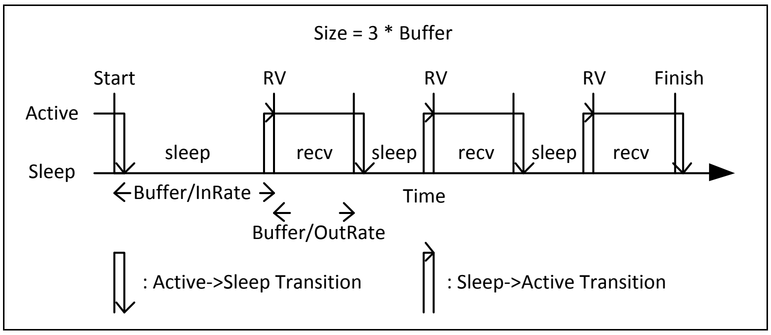

Fig. 1. Example state transitions of a 3*Buffer Size transfer when OutRate equals to 2*InRate.

Based on the above example, the main measures in a general case can be summarized as follows:

- The total transfer duration is:

$$Duration = \frac{Size}{InRate} + \frac{Buffer}{OutRate}$$

- The receiving time for the WNIC of the MR is:

$$RecvTime = \frac{Size}{OutRate}$$

- The actual sleep time considering the WNIC transition time is:

$$SleepTime = \frac{Size}{InRate} - \frac{Size - Buffer}{OutRate} - 2 * \frac{Size * TransTime}{Buffer}$$

- Finally, the energy spent during the transfer can be calculated as:

$$Energy = 2 * \frac{Size * TransTime}{Buffer} * TransPower +$$
$$\left(\frac{Size}{InRate} - \frac{Size - Buffer}{OutRate} - 2 * \frac{Size * TransTime}{Buffer}\right) * SleepPower +$$
$$\frac{Size}{OutRate} * RecvPower$$

The above formulation leads to a number of observations that highlight the tradeoff between energy-conservation and data delivery latency, as dictated by the amount of buffered data. For larger amounts of buffered data, the energy savings are higher, but the delivery latency is higher as well. Furthermore, the amount of data that need to be buffered for the scheme to work is dictated by the specifications of the WNIC (i.e. state transition time) and the amount of excess rate of the outgoing vs. the incoming data flows at the BS. Large transition times and small outgoing-incoming data rate difference require large buffering values in order to exploit the energy-saving potential. In case of multiple active mobile receivers the perceived OutRate for each flow becomes smaller, leading to increased energy expenditure.

3.2 The Rendezvous Mechanism

Statistical Internet traffic is shaped into tactic data delivery through the fitting of our rendezvous mechanism into the DTN overlay. During idle periods the BS refrains from routing incoming bundles to their final destination and simply stores them into local storage. At each rendezvous the next rendezvous time is calculated as follows [18]:

- $BP = \frac{RB}{TBO}$: Expresses the ratio of the received bytes over the desired buffer occupancy (where BP the Buffer Portion, RB the Received Bytes and TBO the Target Buffer Occupancy).

- $SBP = BP - \frac{BP-1}{2}$: Smoothes out the BP value for faster convergence (where SBP the Smoothed Buffer Portion).
- $NextRV = \frac{RI}{SBP}$: The interval until the next rendezvous. If 0 bytes were received during the previous interval, the NextRV is set to twice the duration of the previous interval (where NextRV the Next Rendezvous Rime and RI the Reception Interval).

Once the NextRv has been calculated, the BS fragments all bundles that were partially received during the last rendezvous interval and sends the fragmented bundles to the MR. The last bundle of the burst contains the NextRV in its DTN header. When a bundle containing a next rendezvous value arrives at the MR, the overlay checks if the time to the next rendezvous is sufficient for switching to the sleep and then back to the idle state and, if so, it performs the switching. When the WNIC is suspended, an alarm ensures that the wireless interface is brought back to the active state in time for the next data reception.

In case multiple receivers are present, we experiment with alternative rendezvous strategies at the BS in order to assess the effect of limiting buffer flush overlaps to the energy efficiency of the receivers. The analysis in the previous section suggests that by limiting overlaps, each individual flush would be expedited allowing the receiver to remain active for shorter periods of time, further improving energy efficiency. In our study we consider three alternative rendezvous mechanisms: an isolated mechanism, which sets the rendezvous with each receiver individually based on the previously described algorithm, a combined mechanism, which takes into account scheduled rendezvous' of other receivers, and a time-based mechanism, which schedules rendezvous in a purely time-based fashion.

The combined mechanism is a variation of the isolated mechanism. Overlap detection is achieved by estimating the average flushing duration based on the nominal bandwidth of the wireless link and the TBO (i.e. $FlushingDuration = \frac{OutRate}{TBO}$). At rendezvous time, each buffer's nextRV is calculated according to the original mechanism as described in the beginning of this section. Based on the flushing duration estimation, the BS detects possible overlaps with other flushes and tries to reposition the rendezvous so that overlaps are avoided. The new rendezvous may be scheduled between two flushes, after the end of the last scheduled flush or before the beginning of the first scheduled flush, and may result in shifting the original rendezvous either forward or backward in time. The final choice is made so that the deviation from the original rendezvous time is minimized.

The time-based mechanism completely disregards the TBO parameter. Instead, the rendezvous scheduling is purely time-based and the buffer flushes alternate in equal time intervals. Thus, overlaps are readily avoided since the flushes are scheduled adequately far apart. In this version of the mechanism, the intervals are predetermined based on the network characteristics and the TBO. In future versions, however, the mechanism could be modified so that it dynamically adjusts to changing network conditions.

4 Experimental Methodology

The simulation experiments were carried out using our DTN simulation model, comprising a set of classes implemented in the ns-2 network simulator framework [20]. The model supports both TCP and UDP underlying protocols through a DTN agent, which acts as a store-and-forward module between the application and the transport layers. Simulation experiments were conducted in two main directions: Firstly, we employed a single wireless receiving device and experimented with different application protocols; secondly, we employed multiple wireless receivers and experimented with different transmission scheduling strategies at the BS, focusing on file transfers.

In all experimental scenarios, the BS is connected with the MRs on a 802.11 WLAN, with a data rate of 11 Mbps and a basic rate of 1 Mbps. The TCP packet size is 1460 and the maximum window size 100 packets, while the UDP packet size is explicitly specified in each set of experiments. The energy expenditure for the WNIC of a mobile device is tracked through the inherent energy model of ns-2. The parameters necessary for the energy expenditure calculations are set as follows [21]: transmit power = 1.400 W, receive power = 0.950 W, idle power = 0.805 W, sleep power = 0.060 W and transition time = 10ms [22].

The simulation topology used for our experiments is depicted in Fig. 2. Nodes with the DTN suffix host a DTN agent instance, whereas Rel-IP relays IP traffic. The bandwidth and delay values for the topology links are kept constant for all the experiments at the following values: Src – Rel-IP: 1.5Mbps bandwidth for single data transfers and 1 Mbps for multiple simultaneous data transfers, 100ms delay, Rel-IP – BS: 1.5Mbps bandwidth, 100ms delay.

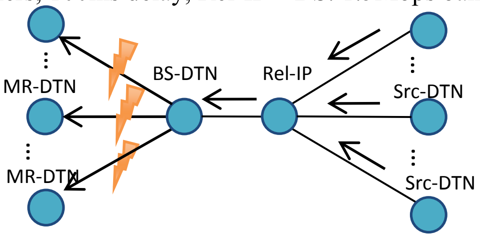

Fig. 2. Simulation Topology

In the first set of experiments we employ the DTN agent in order to evaluate the energy conservation vs. delivery delay tradeoff from a user experience perspective, across the three main types of Internet applications: large file transfers (FTP), media streaming (CBR), and web browsing (HTTP). Data transfers on the overlay follow the Src-DTN→Rel-IP→BS-DTN→MR-DTN path over connections between adjacent DTN nodes. In the end-to-end scenarios a connection is setup directly between a source and a mobile receiver. The traffic characteristics for each application are: FTP – A file size of 10 MB, CBR – A flow sending 500 B every 5 ms (800 Kbps) for 1 minute, and HTTP – A flow sending files of size 20 KB for 2 minutes and 40 seconds. For HTTP connections, a new file is sent as soon as the previous file has finished downloading. HTTP is simulated using a simple application model that assumes no request pipelining [23] and a constant small file size.

In the second set of simulations, multiple simultaneous FTP flows are active, each transferring a file of 10 MB between a DTN source and a DTN-enabled mobile receiver. Namely, the file transfers take place along the network paths: Src-DTN1→Rel-IP→BS-DTN→MR-DTN1, Src-DTN2→Rel-IP→BS-DTN→MR-DTN2, etc. Simulation results are reported for 2, 3 and 4 simultaneous file transfers and for all three rendezvous strategies described in section 3.2 (isolated, combined, time-based). The rendezvous in the time-based case for each TBO are set based on the average measured rendezvous interval for the isolated case for that TBO.

5 Experimental Results

5.1 Single Receiver Multiple Application protocols

The chart in Fig. 3 depicts the energy consumption and the delay for the completion of a 10 MB FTP data transfer for various TBO values, ranging from 10 to 80 KB. The end-to-end case is denoted as E2E and plotted as the first point on the energy and delay lines. The additional delay imposed by the data buffering at the BS reaches a maximum of only 0.4 seconds or 0.7% of the transfer duration for a 80 KB TBO. The energy line on the same chart shows that the consumption drops from 55.5 J in the E2E case to a minimum of 36.2 J for the 80 KB TBO case, yielding a reduction of approximately 34%. These results confirm our previous results [18] that, for relatively large file transfers, substantial energy conservation can be achieved at a negligible performance cost.

TBO	Sleep Count	Sleep Time	Trans Time
E2E	0	0	0
10	232	2.39	4.62
20	521	14.93	10.36
30	348	19.93	6.9
40	262	22.47	5.18
50	212	23.04	4.16
60	176	22.74	3.48
80	134	26.42	2.62

Table 1. FTP with no competing traffic, sleep and transition information.

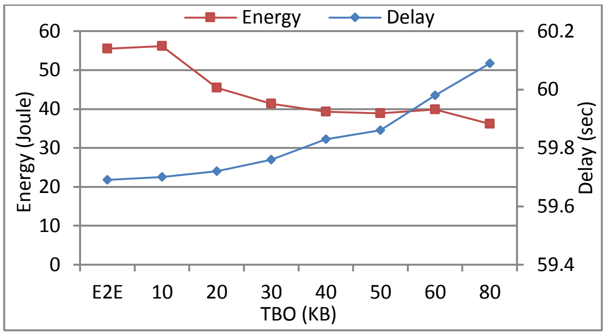

Fig. 3. FTP with no competing traffic energy and delay vs. the TBO.

Table 1 provides information on the number of sleep intervals and the total sleep time and transition time for all TBO values. For the smallest TBO of 10 KB the overall idle time (sum of the sleep and transition time durations) is only 7 seconds. Due to the small TBO, the interval until the next rendezvous time is, in most cases, too short and does not allow enough time for transitioning to and fro the sleep state. For TBO values of 20 KB and larger, the overall idle time is consistently higher than 25 seconds. Maximum sleep time is achieved for the TBO of 80 KB, which also yields the lowest energy consumption as shown in the energy chart.

TBO	Sleep Count	Sleep Time	Trans Time
E2E	0	0	0
10	587	24.15	11.64
20	297	30	5.84
30	199	31.98	3.9
40	153	32.92	2.94
50	123	33.26	2.34
60	100	33.93	1.96
80	77	34.44	1.48

Table 2. CBR with no competing traffic, sleep and transition information.

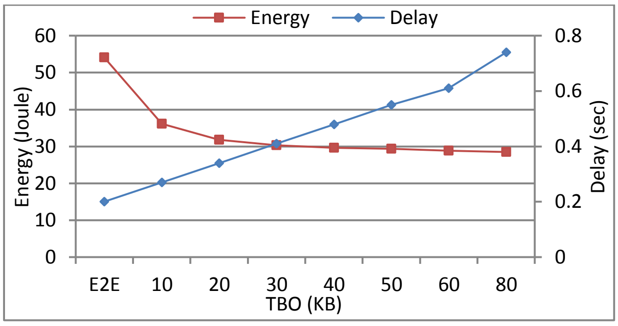

Fig. 4. CBR with no competing traffic energy and delay vs. the TBO.

In terms of the user experience, file transfers are only marginally affected by the deployed DTN overlay and the buffering at the BS introduced by the rendezvous mechanism. The TBO value is usually much smaller than the application ADU (i.e. the transferred file) and so the additional delay is negligible.

Fig. 4 includes the energy consumption and the average delay of delivered datagrams for a CBR flow producing a 500-Byte datagram every 5 ms (800 Kbps) for 1 minute. It is apparent that even for the smallest tested TBO value of 10 KB the energy saving is substantial. Specifically, the energy consumption drops from 54.14 J in the E2E case to 36.15 in the 10 KB TBO case, achieving conservation of 33%. The corresponding average delay values for these experiments are 0.2 sec for the E2E and 0.27 sec for the 10 KB cases respectively; an increase in the order of 26%. In the 30 KB case the energy expenditure drops to 30.32 J (44% reduction), while the average delay is doubled with respect to the E2E case (0.41 sec). The energy conservation reaches a maximum of 47% for the 80 KB TBO case, when the delay is 3.7 times that of the E2E case.

The information displayed in Table 2 shows how the overall idle time (sum of sleep and transition times) remains almost identical (35-36 sec) for all tested TBO values. The additional energy conservation achieved for higher values of the TBO results from the decrease in the overall number of sleep intervals and the consequent reduction of the time spent in the energy-consuming transition state.

The simulation results show that the energy-efficient DTN overlay creates significant energy conservation potential for CBR streaming flows at the expense of a delay increase at the datagram level. However, the additional delay could be compensated in a straightforward way by a small increase in the buffering amount of the client buffering mechanism that is part of most streaming applications. For the 30 KB TBO, where the consumed energy is almost halved, the additional delay was measured at 200 ms, duration that is hardly noticeable by the end-user. Therefore our proposed solution can be applied for most streaming applications with limited adverse effect on the end-user experience.

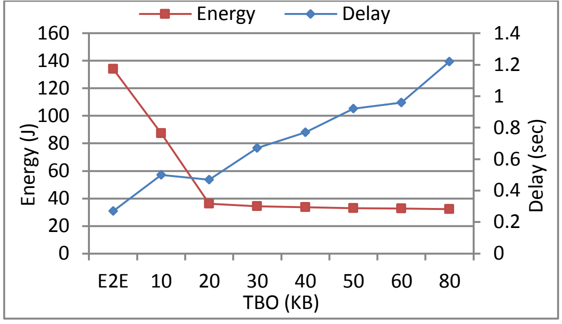

Fig. 5. HTTP with no competing traffic energy and delay vs. the TBO.

The chart contained in Fig. 5 depicts the energy consumption and the ADU delay for a 160-second web browsing session vs. the same TBO values as the FTP and CBR examples. What becomes immediately obvious from the energy-delay chart is that the potential for energy saving is tremendous as the energy consumption drops from 134.1 J in the E2E case to 36.18 J in the 20 KB TBO case, a reduction of 73%. The average ADU delivery latency is, respectively, increased from 0.27 sec in the E2E case to 0.47 sec in the 20 KB TBO case. The large energy saving potential is attributed to the long idle periods between transmissions of successive ADUs that may be readily turned into sleep periods when the rendezvous mechanism is employed. For TBO values larger than 20 KB, the energy consumption only slightly improves with a significant deterioration of the introduced delay. The key value of 20 KB for the TBO coincides with the file size of 20 KB selected for this set of experiments.

Contrary to file transfers and streaming applications studied in the previous subsections, the web browsing user experience is sensitive to the application responsiveness. Furthermore, the additional delay of 200-300 ms introduced by the buffering at the overlay will be actually multiplied by the number of elements included in a web page, resulting in a, potentially unacceptable overall delay. However, modern browsers simultaneously open multiple TCP connections so that the web page elements can be more quickly downloaded reducing the overall delay. All these connections in the DTN overlay are handled collectively so that the TBO refers to the total data amount belonging to all active flows, destined to the same node, mitigating the total delay. In any case, this type of proposed buffering in web browsing applications may deteriorate user experience and, thus, it should be employed with prudence. A possibility would be to only enable this feature with the user's consent, in cases the battery level of the device is running low. This way the device operation could be extended at the expense of an inferior web browsing user experience.

5.2 Multiple Receivers File Transfers

The charts in this section depict the average energy consumption during an FTP transfer for all active mobile receivers for TBO values ranging from 10 to 80 KB, including the end-to-end (E2E) case. Fig. 6 plots the energy consumption for the three rendezvous strategies when two mobile receivers are simultaneously active on the wireless network. For TBO values under 30 KB, the isolated and time-based mechanisms require the same amount of energy in order to complete the transfer, while the combined mechanism achieves of approximately 10%. For higher TBO values the combined mechanism generally stays between the lines of the isolated and the time-based mechanisms, achieving an average improvement of roughly 5 Joule compared to the isolated mechanism. For these values of the TBO, the time-based mechanism consistently achieves an improvement of over 15% with respect to the isolated case.

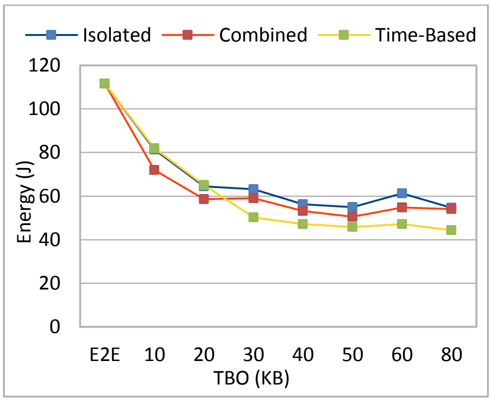

Fig. 6. Energy consumption for 2 Mobile Receivers.

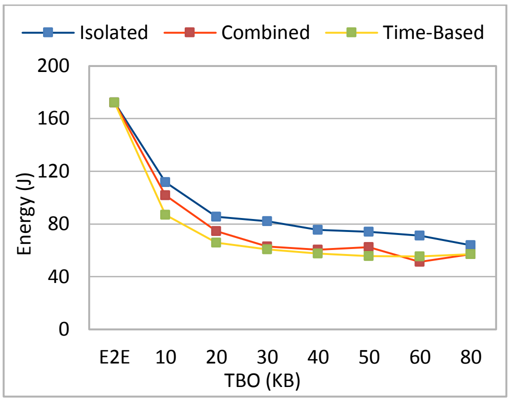

Fig. 7. Energy Consumption for 3 Mobile Receivers.

The results are similar, but somewhat more pronounced, for the case with three mobile receivers as may be seen on Fig. 7. Here, the effect of the mechanisms that limit the overlaps of the buffer flushes to the mobile receivers (i.e. the time-based and combined cases) are even more substantial, improving the energy efficiency of the receivers up to 25% for TBO values between 30 and 60 KB. Moreover, the performance of the combined mechanism largely coincides with that of the time-based mechanism, showing that the flush fitting algorithm effectively limits contention on the wireless LAN.

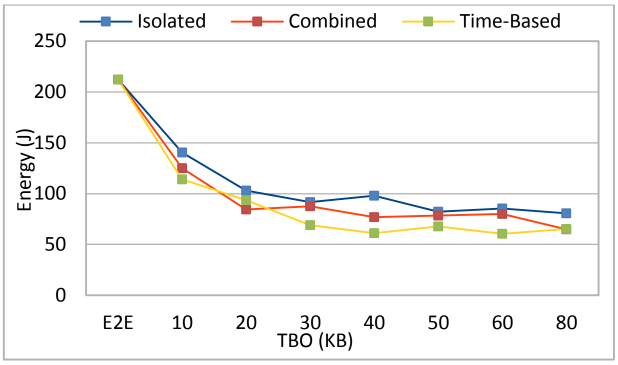

Fig. 8. Energy Consumption for 4 Mobile Receivers.

Fig. 8 depicts the average energy expenditure in the four-receiver case. Again, the time-based mechanism achieves significant energy conservation as compared to the isolated mechanism for TBOs of 30 – 60 KB. On average, the energy efficiency improves by 30% when the time-based mechanism is in place. On the other hand, the combined mechanism does not exhibit a consistent behavior, although it generally achieves better energy efficiency than the isolated mechanism.

The important conclusion that is drawn from the simulation results presented in this section is that, indeed, minimizing overlap of the buffer flushes on the wireless LAN significantly improves the energy efficiency of the mobile receivers. This becomes evident by the performance of the time-based mechanism in all 2, 3 and 4 mobile receivers cases. The combined mechanism also improves energy efficiency over the isolated mechanism to a good extent, despite its relatively inconsistent performance. It is evident that, under certain circumstances, the buffer flushing overlaps are not fully eliminated.

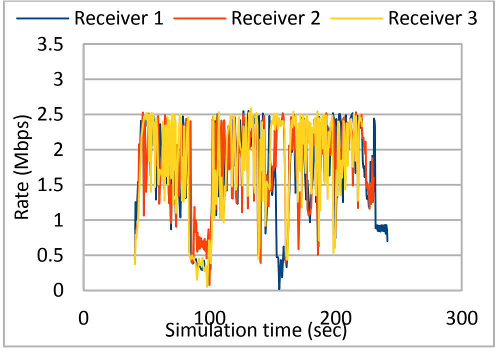

Fig. 9. Buffer Flush Output Rate for the Isolated Mechanism with 3 Mobile Receivers and 40 KB TBO.

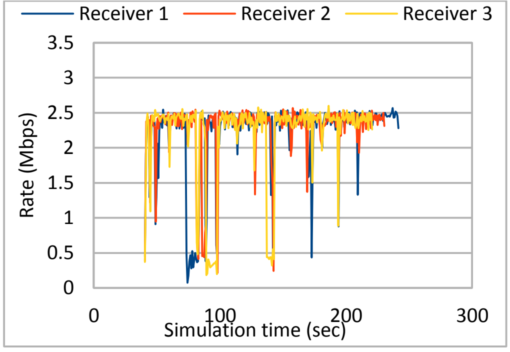

Fig. 10. Buffer Flush Output Rate for the Time-Based Mechanism with 3 Mobile Receivers and 40 KB TBO.

In order to visualize the effect of an overlap limiting vs. the isolated rendezvous mechanism we plotted the actual goodput achieved for each buffer flush in the isolated and time-based cases for 3 mobile receivers and a TBO of 40 KB. The results of Fig. 9 and Fig. 10 show how, for the most part, the goodput of the isolated mechanism fluctuates within a wide range, whereas the goodput of the time-based mechanism is contained within a narrow band slightly below the 2.5 Mbps maximum value. In the isolated case, multiple buffer flushes may be simultaneously active, resulting in lower goodput and, thus, longer duration for each flush, forcing the WNIC to stay active for longer periods of time at each rendezvous. On the contrary, rapid buffer flushes of the time-based mechanism achieve better energy efficiency of the receiver by minimizing the time spent in the idle state.

6. Conclusions and Future Work

Our simulation experiments are in-line with the mathematical formulation and older results in that file transfers are only marginally affected by the DTN overlay operation. Therefore, the proposed energy-efficient solution does not affect the end-user experience and can be unconditionally applied to file transfer applications. With respect to streaming flows, significant energy conservation can be achieved, introducing, however, substantial delays at the datagram level. Since the buffering amount is, generally, larger than the stream datagram, delays are introduced due to the data buffering at the base station. Nevertheless, most streaming applications employ buffering on the client side in order to cope with data rate fluctuations, so the effect of the rendezvous buffering on the end-user experience should be fairly limited, and could be compensated by a slight increase in the client buffering amount. In contrast to file transfers and streaming applications, the user experience during web browsing depends highly on the application responsiveness. Our proposed buffering scheme in the DTN overlay may deteriorate user experience in web browsing applications and, thus, it should be employed with prudence, possibly soliciting the user's consent when the battery level of the device is running low.

When multiple mobile receivers are present, our simulations confirm the implications of the mathematical description that a smart scheduling mechanism that limits overlaps of the buffer flushes further improves energy efficiency as compared to an isolated scheduling approach. Our combined mechanism improves on the isolated approach, but it does not achieve the consistent improvements of the time-based mechanism, suggesting that further development of the mechanism is necessary. It is part of our imminent plans to refine the combined mechanism, mainly in the direction of increasing its flexibility and adaptiveness to changing network condition. Currently, buffer flushing overlap avoidance depends mainly on calculations according to the nominal duration of each flush. We have strong evidence that energy efficiency could be significantly increased if the calculations dynamically adjust based on the load of the WLAN as well as the expected data amount available at rendezvous time.

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