Exploiting SCTP Multistreaming to Reduce Energy Consumption of Multiple TCP Flows over a WLAN

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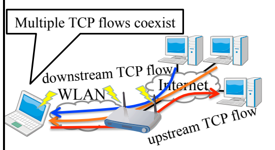
Background

- Accessing the Internet by using mobile devices is becoming common situations
  - Laptops, tablet PCs, smartphones
- Mobile devices are battery-driven
- Wireless communication of a mobile device can account for up to about 50% of its total power consumption

It is important for lengthening the battery's lifetime to save energy in wireless communications

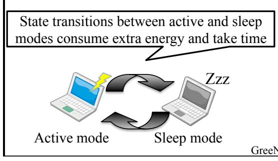
Energy saving in a WLAN

It is effective for energy saving to sleep at idle duration in which data are not being sent or received



When multiple TCP flows coexist on a wireless client, it is difficult to control the sleep timings due to its uncoordinated behavior

We aggregate multiple TCP flows into a single aggregate flow



Frequent state transitions reduces the sleep efficiency

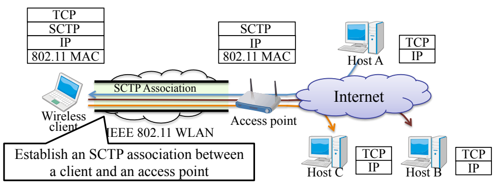
We send and receive packets in a bursty fashion

Objective of this work

Improving energy efficiency of a wireless client in the presence of multiple TCP flows in a WLAN

1. Propose ***SCTP tunneling*** for improving energy efficiency of TCP data transfer over a WLAN
2. Construct a mathematical model for power consumption of SCTP tunneling
3. Show energy efficiency of SCTP tunneling through numerical results

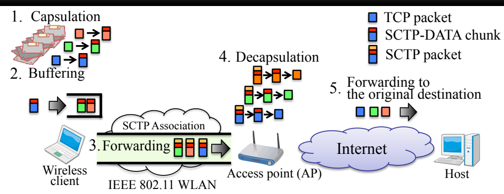
Overview of SCTP tunneling



Two key features

- Flow aggregation
  - SCTP tunneling aggregates multiple TCP flows into a single SCTP association
    - SCTP multistreaming feature is exploited
- Burst transmission
  - SCTP tunneling sends and receives packets of aggregate TCP flows in a bursty fashion
    - Delayed ACK is used

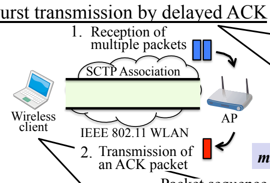
SCTP tunneling - Flow aggregation



1. Each TCP packet generated from an application is encapsulated in an SCTP-DATA chunk.
2. Each SCTP-DATA chunk is enqueued in a single transmission queue of the SCTP association
3. When a new SCTP packet can be sent, an SCTP-DATA chunk is dequeued from the transmission queue and is placed in a single SCTP packet
4. Once the AP receives the SCTP packet, it is decapsulated at the AP
5. The original TCP packet is forwarded to its destination

SCTP tunneling - Burst transmission

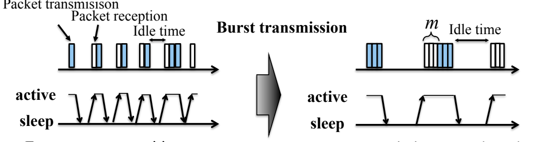
Burst transmission by delayed ACK



1. An reciever sends an ACK packet every m packets received.
2. Once receiving the ACK packet, a sender can send m packets consecutively

m: number of packets sent in a bursty fashion

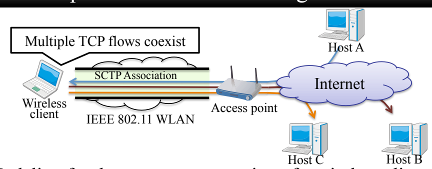
Packet sequence of wireless client during SCTP tunneling



Frequent state transitions reduces the sleep efficiency

Burst transmission can reduce the number of state transitions

Network model and assumptions for modeling power consumption for SCTP tunneling



Modeling for the power consumption of a wireless client in the presence of multiple TCP flows

Assumption

- Average throughputs of TCP flows are given
- Data frames are lost randomly at MAC-level
- A wireless client uses RTS/CTS mechanisms, whereas an AP does not use it.
- A wireless network interface (WNI) has four modes
  - *transmit*, *receive*, *idle*, *sleep* modes
- A WNI can sleep at idle time with exact timings

Overview of power consumption model

Power consumption model for SCTP tunneling

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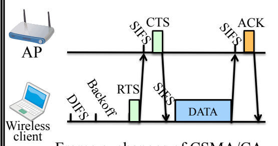
Submodel at MAC-level



Frame exchanges of CSMA/CA

Based on frame exchanges of CSMA/CA, we calculate energy consumption of transmission and reception of one data frame

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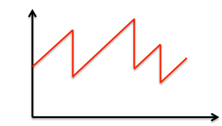
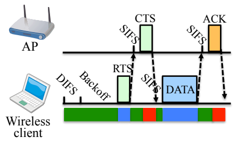
Submodel at SCTP-level



transmission rate of SCTP

We calculate the power consumption based on the number of packets sent at SCTP-level, which depends on the behavior of the congestion control

Energy consumption model for frame exchanges at MAC-level



Probability that a data frame is sent i times

$$Q(i) = \begin{cases} q^{i-1}(1-q) & \text{if } i \leq N \\ q^N & \text{if } i = N+1 \end{cases}$$

q : Probability of transmission failures at MAC-level

N: Maximum number of retransmissions

Expected energy consumption for the i th data frame transmission after (i – 1) failures

Energy consumption during idle time

$$J^t(i) = P^I(3T_{SIFS} + T_{DIFS} + T^{BO}(i) + 4\tau) + P^t(T_{RTS} + T^{client}_{DATA}) + P^r(T_{CTS} + T_{ACK})$$

Energy consumption for frame transmission

Energy consumption for frame reception

Expected energy consumption for one data frame transmission

$$E[J^t] = \sum_{i=1}^{N+1} \sum_{j=1}^{i} J^t(j)Q(i)$$

Power consumption of SCTP tunneling

SCTP congestion control

- SCTP employs a window-based rate control, which is the same as that in TCP
- SCTP congestion control is applied to the entire association, not to individual streams

We can regard the behavior of SCTP congestion control as that for a single TCP flow

We model a power consumption model at SCTP-level based on our previous models [9], [10]

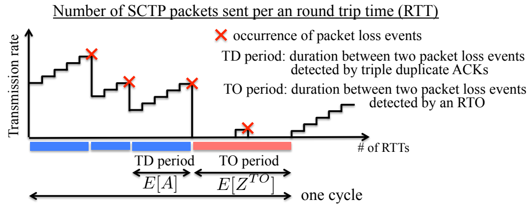
These models derive energy consumption for TCP data transfer over a WLAN based on the detailed behavior of TCP congestion control

9. M.Hashimoto,G.Hasegawa,andM.Murata,"Modelingandanalysisofpowerconsumption in TCP data transmission over a wireless LAN environment," in Proceedings of GreenComm 2011, Jun. 2011, pp. 1–6.

10. ——, "Energy efficiency analysis of TCP with burst transmission over a wireless LAN," in Proceedings of ISCIT 2011, Oct. 2011, pp. 292–297.

Energy consumption of SCTP tunneling

Number of SCTP packets sent per an round trip time (RTT)



Expected power consumption of SCTP tunneling

Expected energy consumption during a TD period

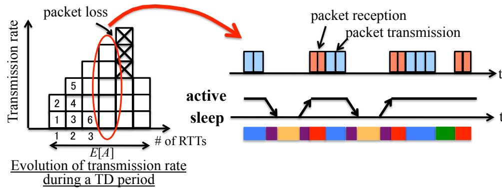
Expected energy consumption during a TO period

$$P = \frac{J^{TD} + Q(E[W])J^{TO}}{E[A] + Q(E[W])E[Z^{TO}]}$$

Expected duration of a TD period

Expected duration of a TO period

Energy consumption during a TD period



Expected energy consumption during a TD period

Energy consumption for SCTP packet transmission

Energy consumption for SCTP packet reception

$$J^{TD} = E[Y]E[J^t] + (E[Y]-E[W]/2)E[J^r] + P^s E[T^s_{td}] + E[N^s_{td}](P^{as}T^{as} + P^{sa}T^{sa}) + P^i\{E[A]-E[Y]E[T^t]-(E[N^s_{td}]-E[W]/2)E[T^r]-E[T^s_{td}]-E[N^s_{td}](T^{as}+T^{sa})\}$$

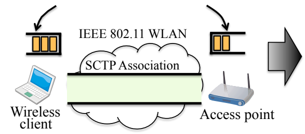
Energy consumption due to state transitions

Energy consumption during sleep time

Energy consumption during idle time

Increase in transmission delay by SCTP tunneling

To send SCTP packets in bursty fashion,
SCTP tunneling needs to buffer SCTP packets at the tunnel inlet



This results in an additional delay for each TCP packet

Average buffering delay at the tunnel inlet

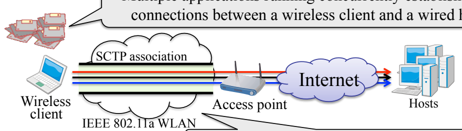
Number of packets sent in a bursty fashion

$$D = \frac{m-1}{2}\frac{1}{R}$$

Arrival rate of TCP packets

Numerical analysis – Parameter settings

Multiple applications running concurrently establish TCP connections between a wireless client and a wired host



Data frames are lost randomly at MAC-level

Parameter settings

- IEEE 802.11a (Data rate: 54 Mbps)
- TCP-DATA packet size: 1500 bytes
- TCP-ACK packet size: 40 bytes

Power consumption of a WNI [12]

Transmit	Receive	Listen	Sleep
1.4 W	0.9 W	0.8 W	0.016 W

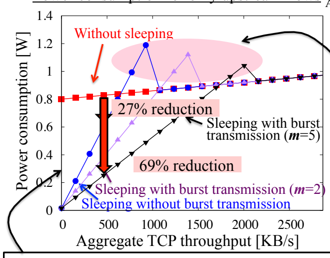
Transition latency from sleep to active: 1ms
Power consumption from sleep to active: 1.4 W

[12] Wistron NeWeb Corp., "CM9: WLAN 802.11 a/b/g mini-PCI Module," available at http://site.microcom.us/CM9.pdf.

Numerical results – Power consumption

Power consumption for only upstream flows

Average TCP throughput per one flow: 150 KB/s
m: Number of packets sent in bursts



The power consumption with sleeping becomes larger than that without sleeping

Energy consumption due to state transitions exceeds energy reduction by sleeping

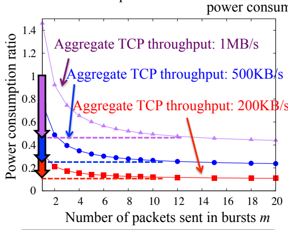
Such a situation can be avoided by staying in active mode when the idle time is insufficient

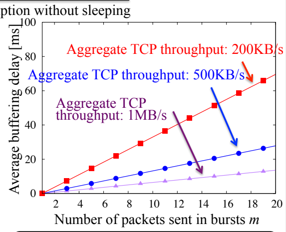
Sleeping can reduce the power consumption significantly
Even when aggregate TCP throughput is large, sleeping with burst transmission can improve the sleep efficiency

To reduce the number of state transitions contributes to improve the sleep efficiency

Numerical results – Trade-off between energy efficiency and transmission delay

$$\text{Power consumption ratio} = \frac{\text{power consumption with sleeping}}{\text{power consumption without sleeping}}$$





As *m* increases, the power consumption ratio converges to a certain value

As *m* increases, the average buffering delay increases linearly

With increased aggregate TCP throughput, the improvement rate of energy reduction by sleeping becomes large compared with the increase rate of average buffering delay

SCTP tunneling with burst transmission can considerably reduce power consumption with increasing moderate delay when aggregate TCP throughput is large

Conclusion and future work

Conclusion

- We have proposed SCTP tunneling for TCP data transfer over a WLAN to save energy of a wireless client
  - Two key features: flow aggregation and burst transmission
- To assess the energy efficiency of SCTP tunneling, we have constructed the mathematical model for its power consumption
- From numerical results, we have demonstrated that SCTP tunneling can considerably reduce power consumption with increasing moderate delay

Future work

- We plan to implement SCTP tunneling on commercial WLAN APs and wireless clients with existing power saving mechanisms