Energy Efficiency Analysis of TCP with Burst Transmission over a Wireless LAN

Masafumi Hashimoto, Go Hasegawa, Masayuki Murata
Osaka University, Japan

Background

- Accessing the Internet by using mobile devices is becoming common situations
  - Laptops, tablet PCs, smartphones
- Mobile devices are battery-driven
- Wireless communications of a mobile device can account for about 10% to 50% of its total power consumption [1]

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

[1] Atheros Communications, "Power consumption and energy efficiency comparisons of wlan products." In Atheros White Papers, May 2003.

Impact of TCP behavior for energy consumption

How do we save energy effectively?

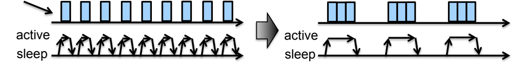
Energy efficiency depends on when and how long a wireless client stays at ***sleep mode***

Timings of packet transmission and reception depend on the behavior of transport-layer protocols used by upper-layer applications

We should understand the behavior of transport-layer protocols for effective energy saving

Energy consumption model for a mobile device in TCP data transfer [9]

To further save energy, we should reduce the number of state transitions between active and sleep modes



[9] M. Hashimoto, G. Hasegawa, and M. Murata, "Modeling and analysis of power consumption in TCP data transmission over a wireless LAN environment," in Proceedings of GreenComm 2011, June 2011.

Objectives of this work

Main idea

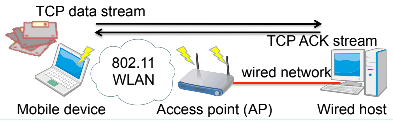
Introduce TCP-level burst transmission that transmit multiple data segments consecutively to lengthen each idle duration

Energy efficiency analysis of TCP-level burst transmission by using energy consumption models

1. Construct an energy consumption model of burst transmission in TCP data transfer by extending the model in [9]
2. Show energy efficiency of burst transmission through numerical results

[9] M. Hashimoto, G. Hasegawa, and M. Murata, "Modeling and analysis of power consumption in TCP data transmission over a wireless LAN environment," in Proceedings of GreenComm 2011, June 2011.

Network model and assumptions for medlling



We model energy consumption of a mobile device in upstream TCP data transfer over WLAN

Assumptions

- Consider TCP bulk data transfer
- Timings of packet transmission and reception are determined by the behavior of TCP congestion control mechanisms, and TCP knows these timings
- Frame collision does not occur in the WLAN, so no frames are lost at the MAC level
- Data segments are lost by congestion in the wired networks, but ACK segments are not lost

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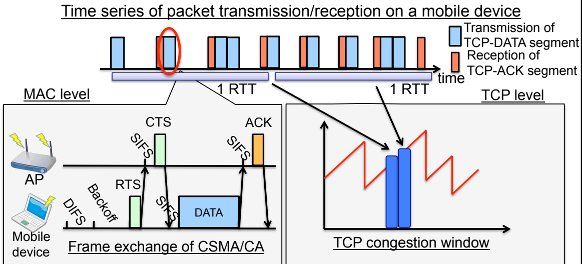
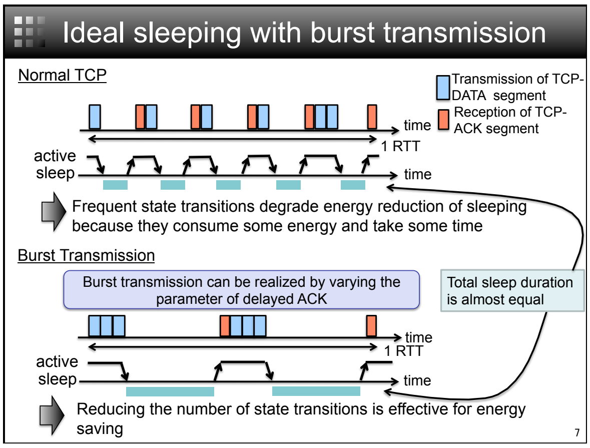
Structure of energy consumption models

Our model is a mixture of the MAC-level model and the TCP-level model



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

The number of packets sent and received in an RTT is determined by the TCP congestion window size



Ideal sleeping with burst transmission

Normal TCP

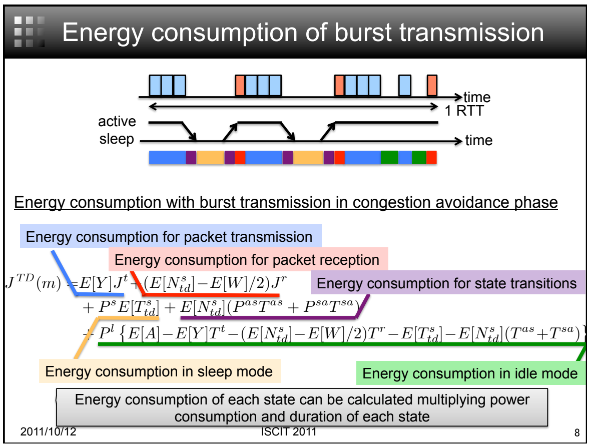
Frequent state transitions degrade energy reduction of sleeping because they consume some energy and take some time

Burst Transmission

Burst transmission can be realized by varying the parameter of delayed ACK

Total sleep duration is almost equal

Reducing the number of state transitions is effective for energy saving



Energy consumption of burst transmission

Energy consumption with burst transmission in congestion avoidance phase

Energy consumption for packet transmission

Energy consumption for packet reception

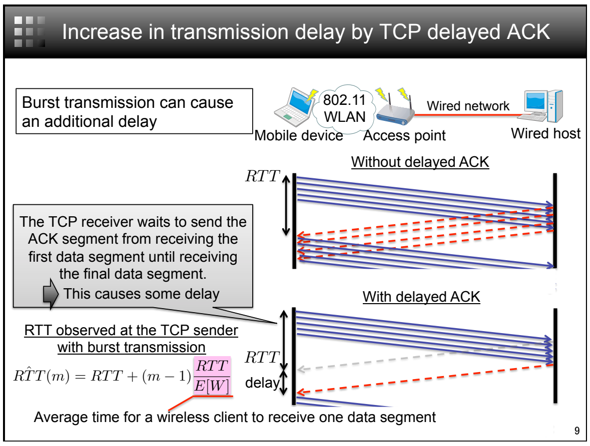
Energy consumption for state transitions

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

Energy consumption in sleep mode

Energy consumption in idle mode

Energy consumption of each state can be calculated multiplying power consumption and duration of each state



Increase in transmission delay by TCP delayed ACK

Burst transmission can cause an additional delay

Without delayed ACK

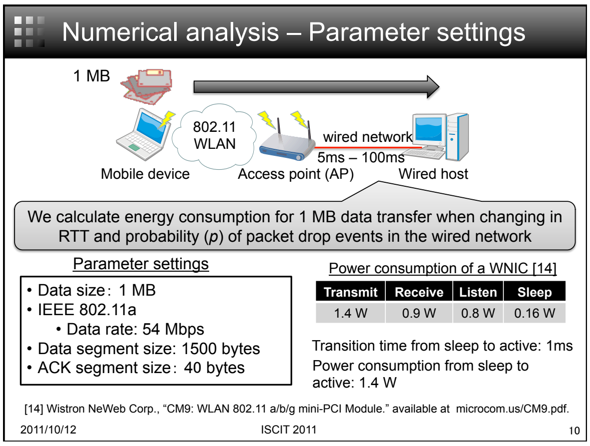
The TCP receiver waits to send the ACK segment from receiving the first data segment until receiving the final data segment.
⇨ This causes some delay

With delayed ACK

RTT observed at the TCP sender with burst transmission

$$R\hat{T}T(m) = RTT + (m-1)\frac{RTT}{E[W]}$$

Average time for a wireless client to receive one data segment



Numerical analysis – Parameter settings

We calculate energy consumption for 1 MB data transfer when changing in RTT and probability (*p*) of packet drop events in the wired network

Parameter settings

- Data size：1 MB
- IEEE 802.11a
  - Data rate: 54 Mbps
- Data segment size: 1500 bytes
- ACK segment size：40 bytes

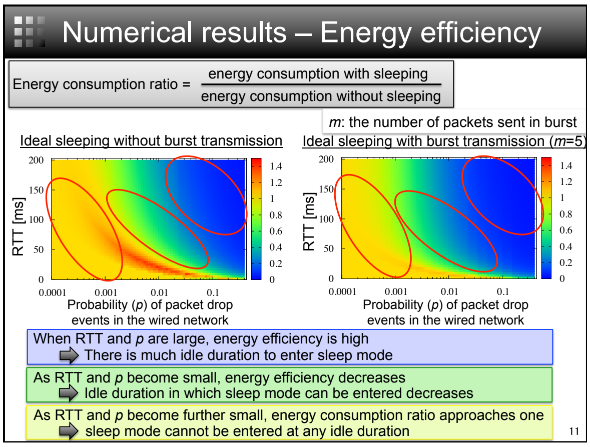
Power consumption of a WNIC [14]

Transmit	Receive	Listen	Sleep
1.4 W	0.9 W	0.8 W	0.16 W

Transition time from sleep to active: 1ms

Power consumption from sleep to active: 1.4 W

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



Numerical results – Energy efficiency

Energy consumption ratio = $\frac{\text{energy consumption with sleeping}}{\text{energy consumption without sleeping}}$

m: the number of packets sent in burst

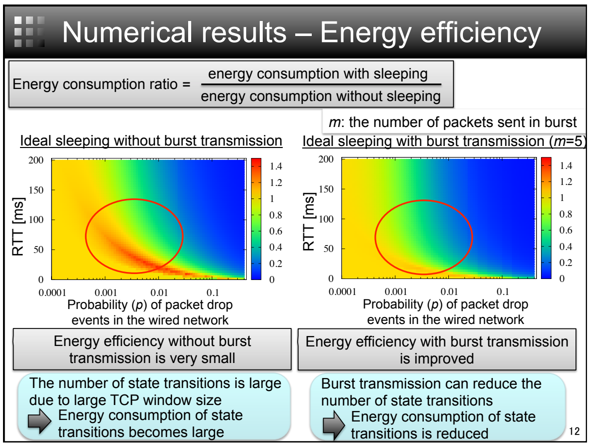
Ideal sleeping without burst transmission

Ideal sleeping with burst transmission (*m*=5)

When RTT and *p* are large, energy efficiency is high
⇨ There is much idle duration to enter sleep mode

As RTT and *p* become small, energy efficiency decreases
⇨ Idle duration in which sleep mode can be entered decreases

As RTT and *p* become further small, energy consumption ratio approaches one
⇨ sleep mode cannot be entered at any idle duration



Numerical results – Energy efficiency

Energy consumption ratio = $\frac{\text{energy consumption with sleeping}}{\text{energy consumption without sleeping}}$

m: the number of packets sent in burst

Ideal sleeping without burst transmission

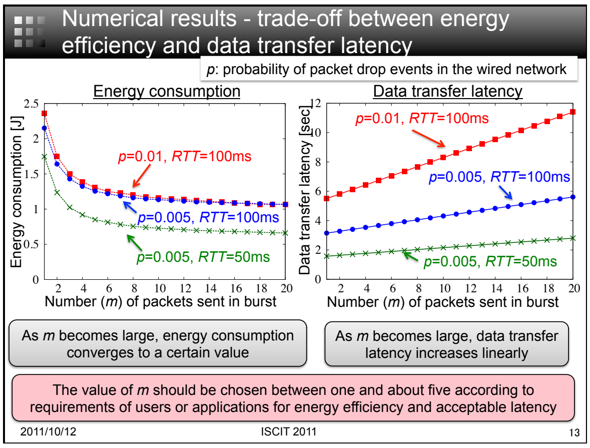
Ideal sleeping with burst transmission (*m*=5)

Energy efficiency without burst transmission is very small

Energy efficiency with burst transmission is improved

The number of state transitions is large due to large TCP window size
⇨ Energy consumption of state transitions becomes large

Burst transmission can reduce the number of state transitions
⇨ Energy consumption of state transitions is reduced



Numerical results - trade-off between energy efficiency and data transfer latency

p: probability of packet drop events in the wired network

As *m* becomes large, energy consumption converges to a certain value

As *m* becomes large, data transfer latency increases linearly

The value of *m* should be chosen between one and about five according to requirements of users or applications for energy efficiency and acceptable latency

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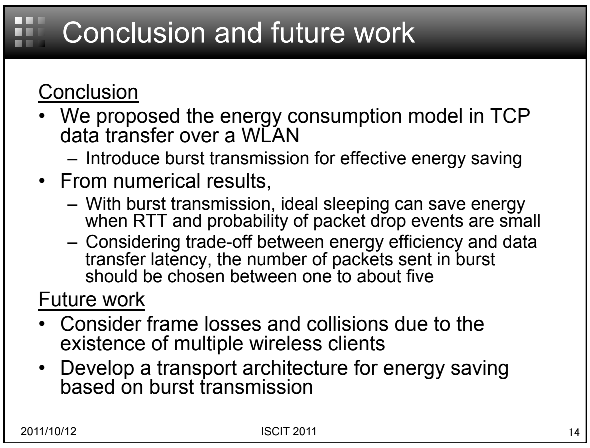

Conclusion and future work

Conclusion

- We proposed the energy consumption model in TCP data transfer over a WLAN
  - Introduce burst transmission for effective energy saving
- From numerical results,
  - With burst transmission, ideal sleeping can save energy when RTT and probability of packet drop events are small
  - Considering trade-off between energy efficiency and data transfer latency, the number of packets sent in burst should be chosen between one to about five

Future work

- Consider frame losses and collisions due to the existence of multiple wireless clients
- Develop a transport architecture for energy saving based on burst transmission

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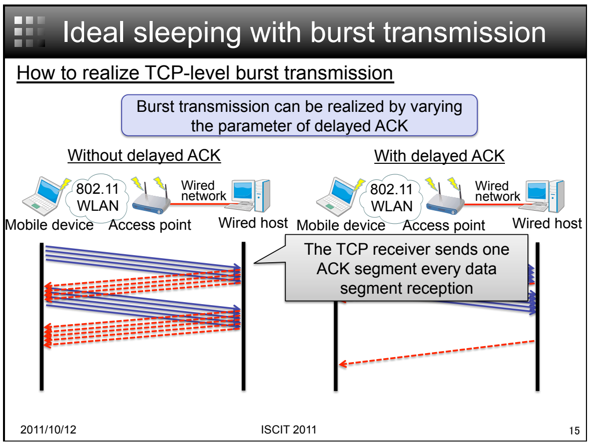

Ideal sleeping with burst transmission

How to realize TCP-level burst transmission

Burst transmission can be realized by varying the parameter of delayed ACK

The TCP receiver sends one ACK segment every data segment reception

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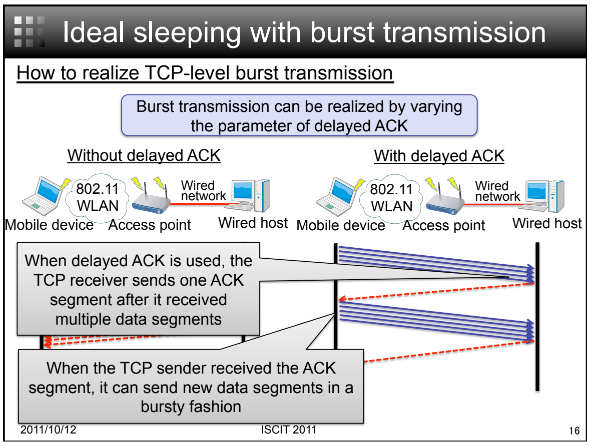

Ideal sleeping with burst transmission

How to realize TCP-level burst transmission

Burst transmission can be realized by varying the parameter of delayed ACK

When delayed ACK is used, the TCP receiver sends one ACK segment after it received multiple data segments

When the TCP sender received the ACK segment, it can send new data segments in a bursty fashion

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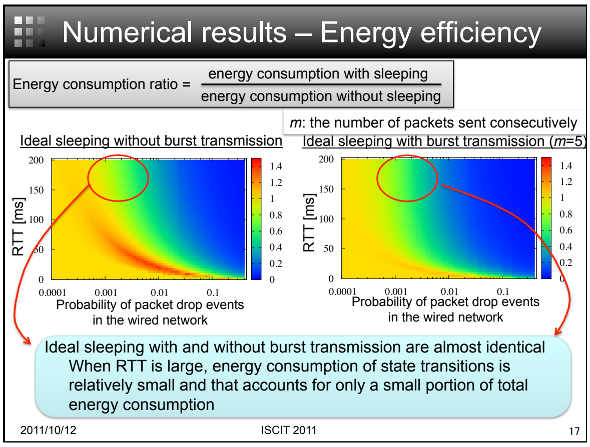

Numerical results – Energy efficiency

$$\text{Energy consumption ratio} = \frac{\text{energy consumption with sleeping}}{\text{energy consumption without sleeping}}$$

m: the number of packets sent consecutively

Ideal sleeping with and without burst transmission are almost identical

When RTT is large, energy consumption of state transitions is relatively small and that accounts for only a small portion of total energy consumption