Politecnico di Milano

Tablet PC power consumption analysis

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Outline

- Virtual Campus
- Power consumption in mobile systems
- The proposed methodology
- Related work
- The experiments
- Experimental results
- Future work

Virtual Campus: Goals

- To support design, composition, and reuse of *Learning Objects* (LOs).
- To support fruition of Learning Objects:
  - Traditional and ad-hoc settings.
  - Personal and cooperative usage.
- To support analysis of students' behavior (learning, relational, and normative aspects).
- To analyze power consumption in all envisaged scenario.
- To experiment the usage of our learning platform and of advanced learning objects in our CS courses.

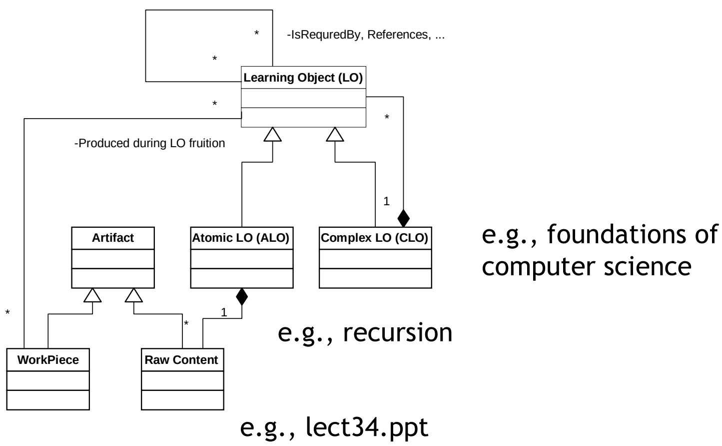
Virtual Campus: Relevance

- Development of a conceptual model that extends the IEEE LOM.
- A prototype that integrates various competences (software engineering, database, hypermedia, hardware design).
- Usage of innovative and consolidated technologies from MS and Politecnico di Milano.

Virtual Campus: usage scenarios

- Actors:
  - Learners, Authors, Organizers, Teachers, Tutors, LO evaluators, Guest learners, Guest teachers, System administrators.
- Authors and Organizers prepare LOs starting from raw content.
- Teachers customize LOs and use them in their classes.
- Learners attend classes:
  - Self fruition of learning objects.
  - Asynchronous cooperation with teachers, tutors, and other learners.
  - Synchronous one-to-one, one-to-many, many-to-many cooperation.
- LO evaluators evaluate system and LOs performance.

The Virtual Campus Learning Object Model (VC LOM)



VC LOM

- Atomic and complex learning objects are described by metadata
  - Typical learning time, cooperation flag, supervision mode, …
- The VC LOM defines the metadata to be provided for each kind of LO.
- It is an extension of the IEEE LOM.
- VC LOM provides precise semantics for relationships among LOs:
  - A language for expressing relationships has been defined.
- It allows definition of preconditions and postconditions:
  - Temporal (e.g., starting date, course duration, etc).
  - Administrative (e.g., learners must have given ICS43).
  - Didactical (e.g., keywords).

Definition of Learning Objects

- Three levels of abstraction:
  - **Reusable-Content Level.** At this level authors prepare reusable LOs by exploiting the LO Language.
    - E.g., a general purpose foundation on computer science course.
  - **Didactical Level.** At this level teachers customize LOs and add constraints that affect the fruition paths at runtime.
    - E.g., they customize the foundation on CS course for mechanical engineering students
  - **Fruition Level.** At this level more specific information are added to LOs (e.g., the 2002-2003 course calendar).

Virtual Campus: evaluation

- We have monitored a 12 hours Lab course where 37 students have been working at the development of a software engineering project in a wireless setting using tablet PCs and Peerversy. Goals:
  - To evaluate power consumption in a wireless highly interactive scenario
  - To analyze students' behavior
  - To test Peerversy functionality and robustness
  - Evaluation results: to be analyzed
- Further evaluations will involve other courses in our curricula (web design, database, foundations on computer science) and will exploit the overall VC platform

Virtual Campus: wireless networks

- Usage of the Virtual Campus learning platform may happen from different types of hosts
  - Students may connect to the platform with their laptops using a wireless network card
  - It may also be possible to use other types of hosts, such as handheld devices
- Power consumption is therefore an important issue, since such devices are usually battery operated
  - Uptime may be crucial in order to be able to complete activities that require a long time
  - Power management may be designed based on the peculiarities of the platform

Power consumption in wireless networks

- Since wireless devices are usually battery operated, power consumption is an important issue
- There are three main sources of power consumption in a wireless network
  - The power used to establish connections
  - The power used for transmission
  - The power consumed while receiving packets
- For each source of power consumption optimizations are possible either at network level or at operating system level
- Goal: reducing the overall power consumption in the network

Connection power

- In wireless networks with infrastructure, devices may sleep until they need to connect to an access point
  - This task is therefore very power efficient
- In Ad-hoc networks the problem is difficult to solve
  - Periodically awakening from sleep mode in order to listen to connection requests may limit power consumption at the paged unit
  - The paging unit may need to repeatedly send the connection request, thus wasting power
  - The overall power consumption may, in some cases, grow with the sleeping time

Transmission power

- Two main approaches have been proposed in the literature
  - Controlling transmission power
    - Reducing transmission power decreases the average power consumption per packet
    - Retransmission rate may grow, potentially overcoming the attained power reduction
  - Network partitioning
    - Having each device communicate directly just to its neighbors allows reducing transmission power
    - Retransmission rate may not be affected
    - Since the received power decreases quadratically with the distance, splitting communication in many hops reduces the overall power consumption

Receiving power

- The hardware that is used for receiving packets, may consume a large amount of power, especially in high bandwidth wireless networks
- Power is consumed for being able to receive packets, not only while receiving packets
- Some wireless protocols turn off the receiver when they realize that the ongoing packet is not addressed to that node
  - A very short header is used for this purpose
  - The receiver is turned off while that packet is on air

Our approach

- Our approach: obtaining experimental results as the starting point for policy definition
- Our point of view is independent of hardware technologies, architectures and device type
  - May be exported on different wireless network or different devices (e.g. handheld devices)
- Goals:
  - Identification of particular activities that have great impact on power consumption with respect to power consumed while receiving packets
  - Proposal of methodologies aimed at reducing power consumption based on the collected data

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Proposed methodology

- Firstly user activities are identified
- Each identified activity is profiled as far as network usage is concerned
- Activities are then classified based on the collected data
- A relationship between classes of activities and power consumption is derived
- All collected information are then used for creating a power-saving strategy

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Related work: transmission power

- Past and ongoing work about the reduction of transmission power is based on the minimization of transmission power holding some constraint
- If it is possible to measure noise, that measure is used to guarantee a good signal to noise ratio
- Indirect measures of noise are based on the feedback at the receiving node about the signal to noise ratio or the required retransmission rate
- Transmission power is dynamically adjusted so as to keep it as low as possible guaranteeing a good signal

Related work: network partitioning

- This approach is based on the idea that each node can directly communicate with its neighbors only
  - Minimum power transmission is thus required for a good signal to noise ratio
- Full connectivity is guaranteed by routing packets among the devices
- Routing is decided based on power-aware metrics
  - Minimum total power
  - Minimum battery cost (the cost increases as the remaining battery capacity decreases)
  - Mixed approaches based on thresholds on remaining battery capacity

Our point of view

- **Power consumed while receiving packets** may be a significant portion of the overall consumption
  - Since all packets are broadcasted, power is consumed even while receiving packets addressed to other devices
- Reducing this source of power consumption allows increased efficiency while not affecting other goals
- This approach is the most hardware-independent and may be applied to all kinds of wireless networks

Experiment 1: network usage

- During the first Virtual Campus course, connectivity among tablet PCs was provided by a wireless network
  - Two different networks configurations were considered: ad-hoc and managed
- One of the goals of this experiment, was to collect data about network usage in this scenario
  - Cooperation was a key issue in this lab course: students had to interact with each other in order to design, develop and test their application
  - All network activity was monitored

Experiment 1: the tools

- Network usage was monitored using TDIMon by Sysinternals http://www.sysinternals.com
- The tool logs all activity at the Transport Driver Interface (TDI) level
- Interface to all protocol stacks such as TCP and UDP
  - Allows monitoring of all network related operations
  - Independent from the transport protocol in use
  - Provided information include
    - Time
    - Process
    - Request type
    - Local and remote end point

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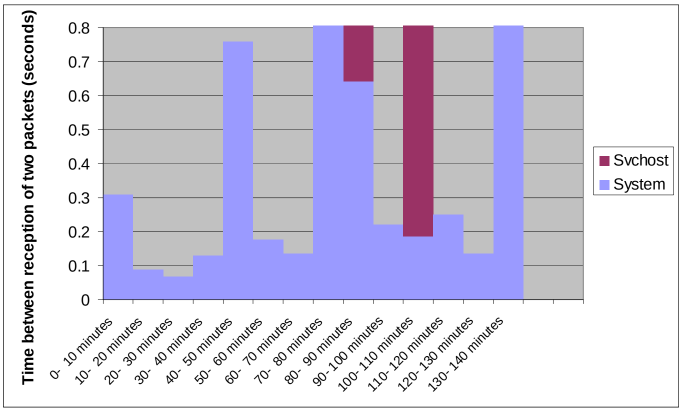
Experiment 1: results (1)



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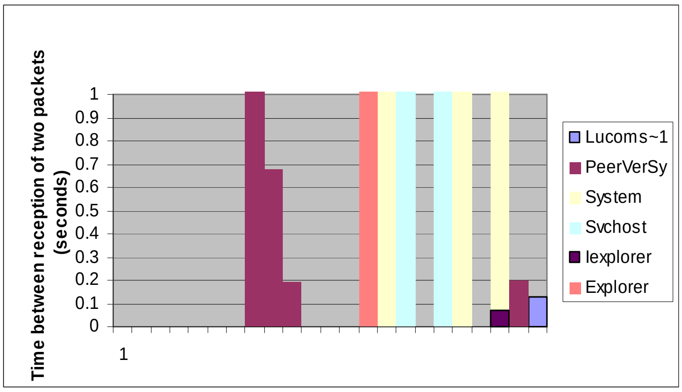
Experiment 1: results (2)



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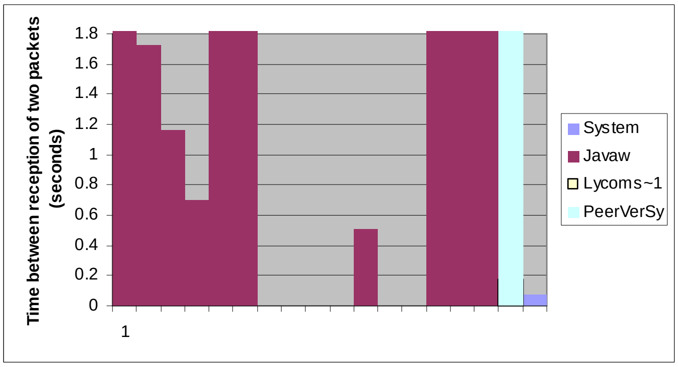
Experiment 1: results (3)



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Experiment 1: conclusions (1)

- First session
  - The networks was used very little
  - Most of the traffic was due to network protocols (ad-hoc networking)
- Second session
  - Traffic was mostly due to Peerversy
  - Bursts of traffic at long time intervals
- Third session
  - Higher traffic
  - Traffic is sustained for a long time

Experiment 1: conclusions (2)

- Three power states can be identified
  - Network is almost unused
    - Network devices may be shut down for long periods
  - Network is used in short bursts
    - Network devices may be shut down for short periods
  - Network is fully used
    - Network devices must be fully operative
- Strict correlation between user activities and power state

Experiment 1: conclusions (3)

- A model similar to ACPI may be used in order to save power
  - Depending on the user activities, the network device may be driven to the corresponding power state
  - It is possible to have applications know about this power-saving feature and drive it
  - For example, applications that allow fruition of the Virtual Campus platform, may choose the correct state depending on the activity the student is carrying on

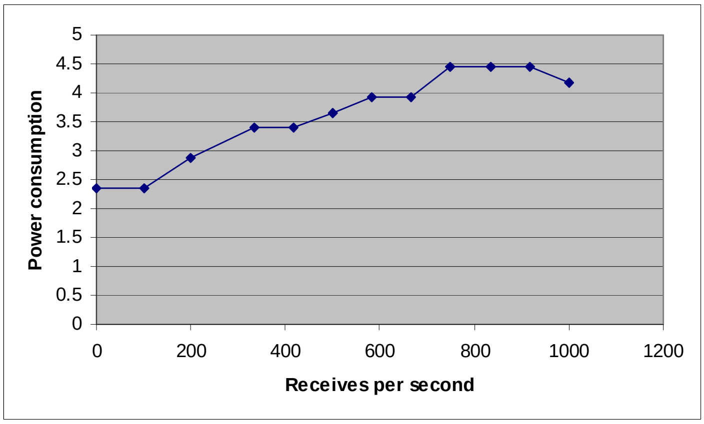
Experiment 2: traffic generation

- The goal of this experiment is to study the relationship between network traffic and power consumption
- Different traffic conditions are generated between two tablet PCs connected in ad-hoc mode
  - The involved PCs are the only nodes of the network
  - No traffic due to resource sharing protocols
  - All packets are due to the test application
  - Random data are sent from one PC to another one at different rates

Experiment 2: power estimation

- Battery information is read by a Visual C++ application based on the ACPI support provided by the platform SDK
- Remaining battery capacity is logged
- Granularity: 1/100 of the overall battery capacity
  - This limitation prevented us from measuring power consumption at a given time
  - Average power consumption is considered

Experiment 2: results



Experiment 2: conclusions

- Increasing data rates by a factor of 10 causes power consumption to increase by a factor of about 1.8
  - Power consumption at low data rates is the same as power consumption with no traffic
  - Low overhead due to packets
- At low data rates power consumption per packet is much higher than the same figure at high data rates
  - Strong inefficiency
- Results confirm the need for an ACPI-like power management policy

Future work

- High level modeling of power consumption based on how activities are related to power consumption
- Proposal of a management policy based on the obtained state-based model
  - Identification of actions to be performed upon state transitions