Lecture 15
Summary & Exam info

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&

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Lecture plan

- Summary of course content
  - HW nodes, Energy and Power (JKM)
  - Protocols (QZ)
- Exam info
- Course evaluation
  - The students will automatically receive the evaluation-form, within a week.

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Summary of content

HW sensor nodes & Energy/Power

(JKM)

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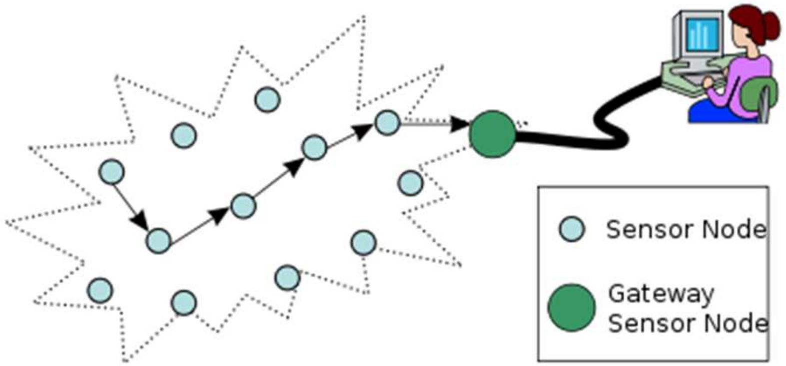
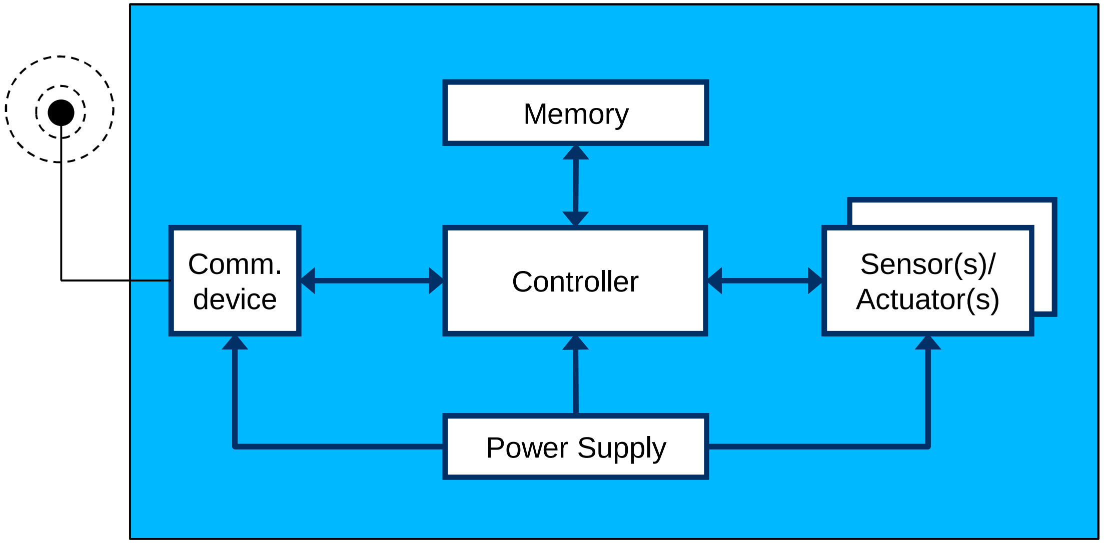
Sensor node architecture (again & again)



- Three characteristics:
  - Sensing
  - Processing
  - Communication
- Five major components:



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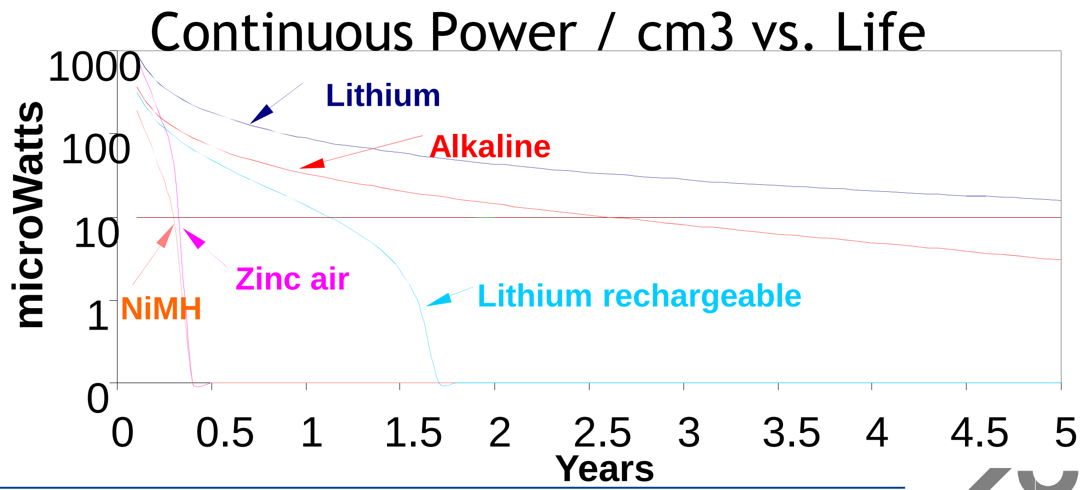
Power Problem (example)

- At an average power consumption of *100 μW*, you need slightly more than *1 cm3* of lithium battery volume for *1 year* of operation, assuming you can use 100% of the charge in the battery.
- Energy density of rechargeable batteries is less than half that of primary batteries.
- So, someone needs to either replace batteries in every node every ~ 9 months, or recharge every battery every 3 to 4 months.
- In most cases, this is not acceptable.



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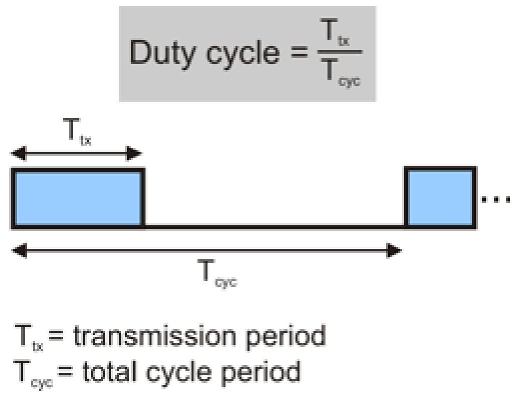
Power Problem “solution”

- What can we do?
  - Utilize that most of the time the Sensor node has nothing to do!
  - Turn it off, i.e. go into sleep when nothing to do and wake up again when required
    - External stimuli
    - Timer
  - Known as Duty-Cycling
    - Active (e.g. 1%)
    - Sleep (e.g. 99%)



  - Combine this if possible with energy harvesting (e.g. solar), i.e. recharge battery continuously even when system is sleeping

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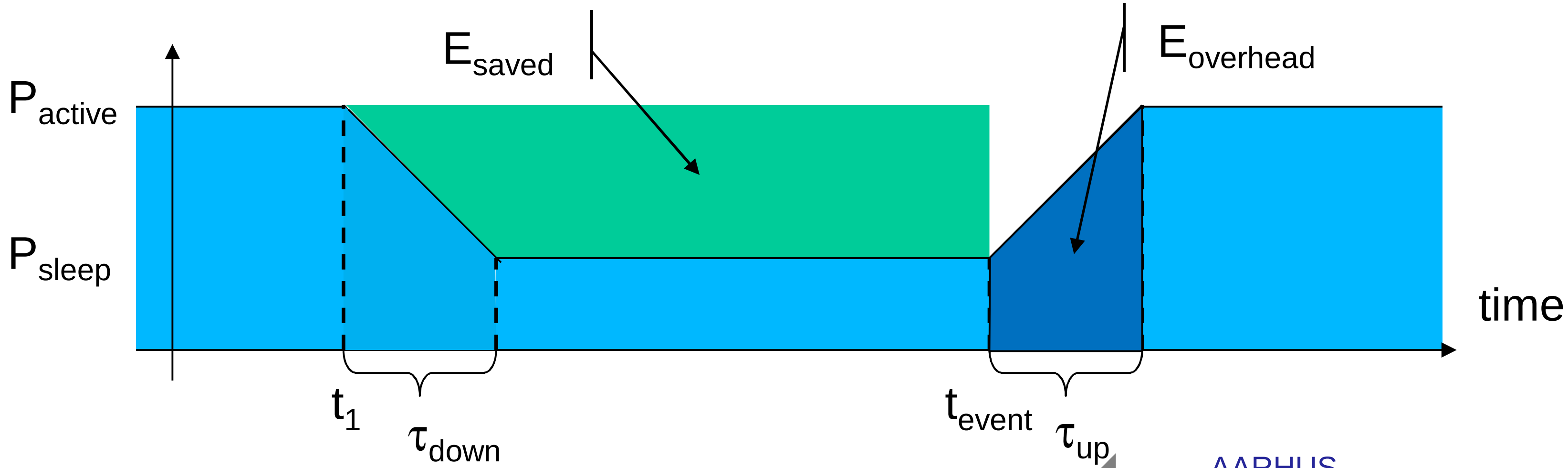
Switching between operation (consumption) modes

- Simplest idea: Greedily switch to lower mode whenever possible
- Problem: Time and power consumption required to reach higher modes not negligible
  - Introduces overhead
  - Switching only pays off if $E_{saved} > E_{overhead}$
- Example: Event-triggered wake up from sleep mode



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Some energy consumption figures

- TelosB Mote
  - TI MSP 430 (@ 1 MHz, 3V) microprocessor:
    - 300 µA active (~1mW)
    - 0.5 µA standby/idle (~1.5µW)
    - 0.1 µA power down /deep sleep(~0.3µW)– only woken up (1µS) by external interrupts (not even timer is running any more)
  - TI Chipcon CC2420 radio:
    - Active Rx 18.8 mA, Tx 17.4mA (0dBm)
    - Idle 0.4mA, Sleep 0,02mA
- Energy ratio of “sending one bit” vs. “computing one instruction”: Anything between 220 and 2900 in the literature
- Hence: try to compute instead of communicate whenever possible

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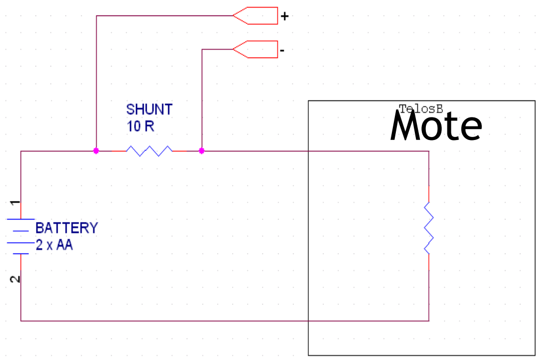
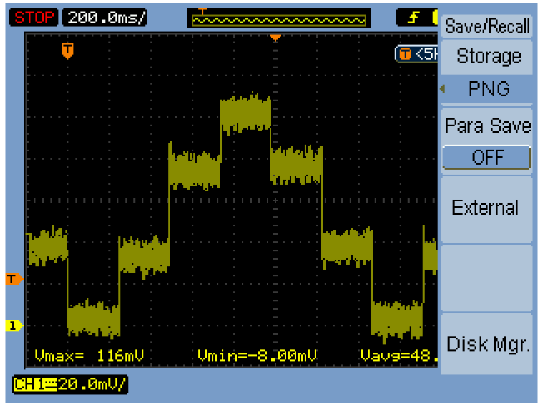
How can we measure – Power & Energy consumption (1/2)





- Goal to investigate Energy & Power of the Mote
- The power consumption by the Mote at any time *t* is:

$$Pmote(t) = Umote(t) \cdot Imote(t)$$

- Energy consumed by the Mote during the time frame from t0 to t1:

$$Emote = \int_{t0}^{t1} Pmote(t) \cdot dt$$

- So we need to find *Umote(t)* and *Imote(t)!*

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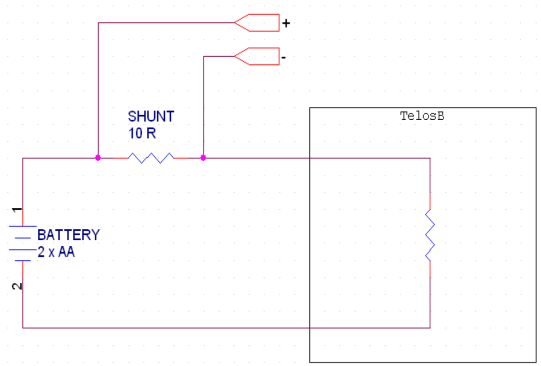
How can we measure – Power & Energy consumption (2/2)

- The voltage across the Mote is then given by:

  $$U_{mote}(t) = U_{battery}(t) - U_{shunt}(t)$$

  where *Ubattery(t)* is the total battery voltage of the 2xAA batteries in series.



- Relation between the Mote current consumption *Imote(t)* *(=Ishunt(t))* and the (small) voltage across the shunt resistor:

  $$U_{shunt}(t) = Rshunt \cdot Imote(t)$$

  where *Rshunt* is the value of the shunt resistor.

- If we assume these values are constant (what if not?) in the time frame *t0* to *t1* we get:

  $$Pmote = (Ubattery - Ushunt) \cdot Ushunt/Rshunt$$

  $$Emote = (Ubattery - Ushunt) \cdot Ushunt/Rshunt \cdot (t1 - t0)$$

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Summary

- For WSN, the need to build cheap, low-energy, (small) devices has various consequences for system design
  - Radio frontends and controllers are much simpler than in conventional mobile networks
  - Energy supply and harvesting are still (and for the foreseeable future) a premium resource
  - Power management (switching off or throttling down devices) crucial
  - Try to compute instead of communicate whenever possible

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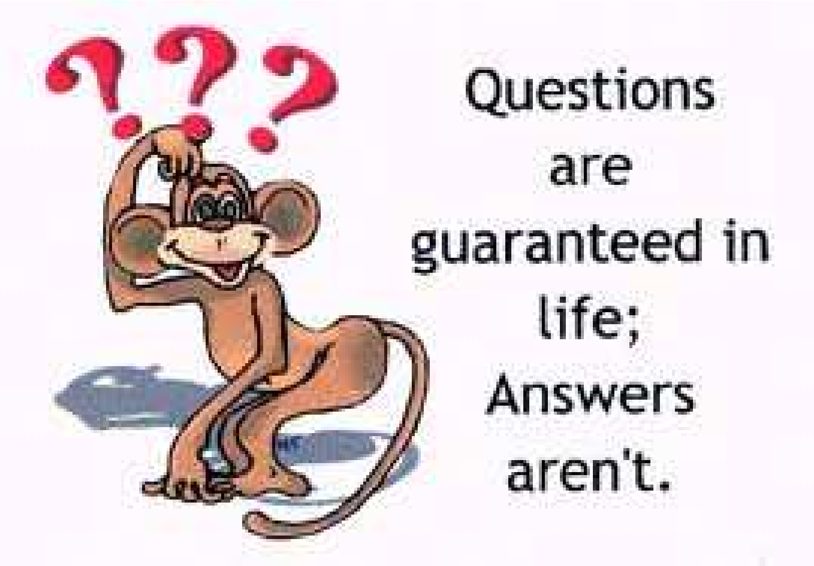

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Summary of content

Protocols and Architecture of WSN

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Constraints in WSN

- Constraints of sensors
  - Limited energy
  - Limited processing power
  - Limited memory capacity
  - Unreliable nodes

- Deployment constraints
  - No detailed network plan

- Environment constraints
  - Harsh radio environment
  - High error rate over a wireless channel

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Network architecture

- Optimization goals
  - **Quality of Service**
  - **Energy Efficiency**
  - **Scalability**
  - Robustness
- Design principles
  - Distributed Organization
  - In-Network processing
  - Adaptive fidelity and accuracy
  - Data-centricity

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MAC

- Main objectives of WSN MAC protocols:
  - Collision Avoidance
  - Energy Efficiency
  - Scalability
- Energy problems
  - ***Collisions*** – wasted effort when two packets collide
  - ***Overhearing*** – waste effort in receiving a packet destined for another node
  - ***Idle listening*** – sitting idly and trying to receive when nobody is sending
  - ***Protocol overhead***

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Contention based MAC protocols

- CSMA and CSMA/CA are the base for many other MAC protocols
- SMAC
  - How does SMAC deal with the four energy issues?
  - Some interesting mechanisms of SMAC, e.g.,
    - Sleep/listening
    - Synchronization
    - Message passing
- BMAC
  - Clear Channel Assessment (CCA)
    - What is CCA used for? When and how to do CCA?
  - Low power listening (LPL)
    - What is LPL? how to do LPL?

Link layer

- One of the important task
  - Reliability in single hop link

- Error control:
  - ARQ
  - FEC
  - ARQ vs. FEC
  - Tradeoffs between FEC & ARQ & transmission power & packet size

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Data centric networking

- SPIN
- Directed Diffusion
  - Interest Propagation
  - Gradient Setup
  - Gradient Reinforcement
  - Data Delivery
- SPIN vs. Directed Diffusion

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Data aggregation

- Why can we do data aggregation? And Why do we need to do data aggregation?
- What are the advantages of data aggregation?
- How to do data aggregation?
- What are the challenges of data aggregation?
- Pros and cons of data aggregation.

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Transport layer

- Transport layer
  - E2E Reliability and E2E Congestion control
- Pump slowly fetch quickly (PSFQ)
  - User node broadcasts data with large inter-packet gap time.
  - Intermediate nodes store packets, forward if in-sequence.
- Event-to-sink reliable transport (ESRT)
  - Exploiting spatial correlation, accepting not 100% packet delivery.
  - How sink updates the reporting rate.
- Congestion detection and avoidance (CODA)
  - Congestion detection.
  - Open-loop hop-by-hop backpressure.
  - Closed-loop multi-source regulation.

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Physical layer

- Questions regarding basic PHY layer knowledge such as path loss, RSSI, modulation and others, will be asked during the oral examination if it is relevant in the context or relevant to the mini-project

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You have learned basics of…

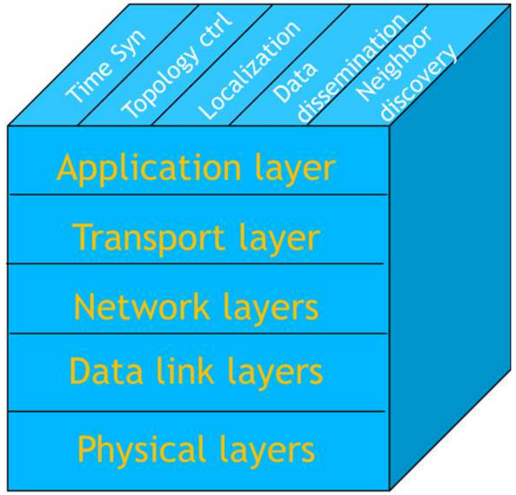
- Optimization goals
- Design principles
- WSN characteristics and constraints
- What are tradeoffs and how to make tradeoffs
- “Qualitatively” not too much “Quantitatively”

In the future…

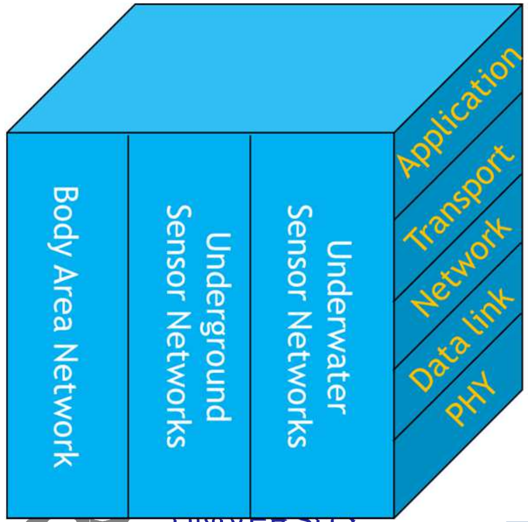
- Apply the basics to a specific application or an application domain
- Not only “Qualitatively” but also “Quantitatively” based on the given assumptions
- Implement your own applications
- Design your own protocols by either implementation or simulation

Q2: TIADEM1 Advanced Embedded Sensor Networks

- Some advanced topics, e.g.,
  - Time synchronization
  - Topology control
  - Localization
  - Neighbor discovery
  - Compressive sensing
  - Etc.



- Categorized by different physical channel characteristics, e.g.,
  - Body Sensor Networks
  - Underground Sensor Network
  - Underwater Sensor Network



Exam - Info

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Course learning outcomes and competences

- ***identify*** and ***describe*** wireless sensor networks, components, and their applications,
- ***explain*** and ***compare*** different wireless sensor networks, architectures and protocols,
- ***explain*** and ***analyse*** power and energy challenges and scavenging methods,
- ***compare*** and ***discuss*** design metrics and constraints,
- ***design*** and ***implement*** wireless sensor networks.

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Project work

- Report turn-in: Sun 7/6@23:59!!!
  - **~15** (max 20) **pages, 11 font size**
    - Main contribution & main challenges & lessons
    - Intro., Theory, Measurements, Data Analysis, Etc.
    - Extra info in appendices
  - **Electronic (pdf) version** (5Mbyte) and source code on BlackBoard – Assignment (Mini-project hand in)
- REMEMBER – return!!!!
  - Sensor motes including power add-on prints to Qi between 15-16 June!!!
  - Otherwise ……

Examination & Evaluation

- Requires completed: project & report (all)
- Individual oral examination (20 mins incl. grading) with no preparation
  - Examined in English covering both:
    - General topic (list of questions – see next-next slide)
    - Project topic/work
      - Must be able to answer questions in the **whole** project report
  - Syllabus material are not allowed for the exam, but
    - **5 keywords per question!!!** (if more - notes will be taken)
    - project report
- Grade – an **overall** grade by use of 7-scale
  - Includes both project report and oral performance (report and question)
  - External censor

Examination & Evaluation (continued)

- Dates:
  - Wednesday 17/6-2015: 9:30-17:00
  - Thursday 18/6-2015: 8:00-17:00
  - Friday 19/6-2015: 8:00-15:00
- Exact exam-list will be available tomorrow on Blackboard, i.e. 28.5.2015 (latest eod)
  - Date & time-slot
  - REMARK
    - Will not be the one generated from the study administration
    - Follow group order
    - Taking care of some of the other exams
- Room: 009C-S, Finlandsgade

Syllabus & Exam Questions

- Lecture slides, notes, articles and chapters/sections of the text book
- Exam questions
  - ~8-9 questions, e.g one question.
    - What are the optimization goals of WSN? What are the basic design principles in WSN? Give one or two examples which can reflect the design principles.
- For details see doc:
  - TIWSNE-Q4-2015-examination questions and syllabus
  - Will be available tomorrow on Blackboard, i.e. 28.5.2015 (latest eod)

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Advice

- Remember to be well prepared and be in good time before your "time slot"

The exam is the party-day for the "well-prepared"

Thanks & Good luck

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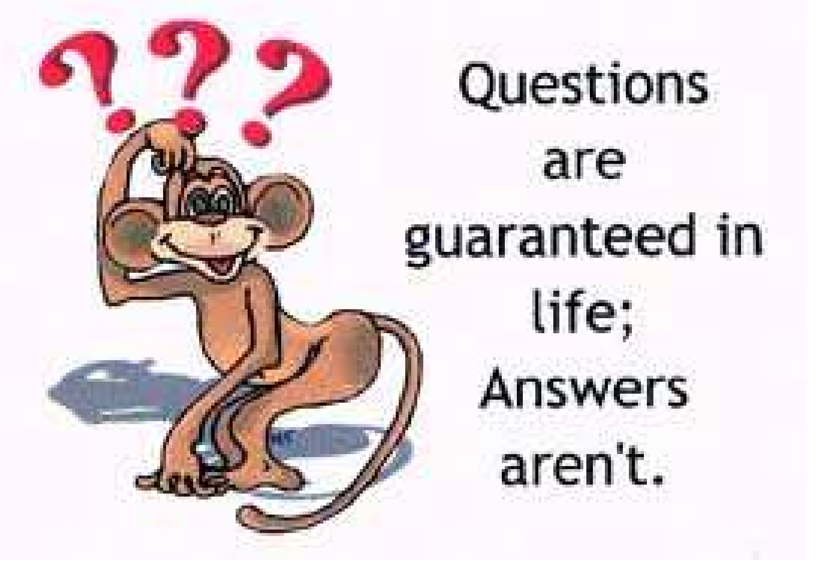

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