ETH
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DTN and Opportunistic Networking Concepts for EE Wireless Networks

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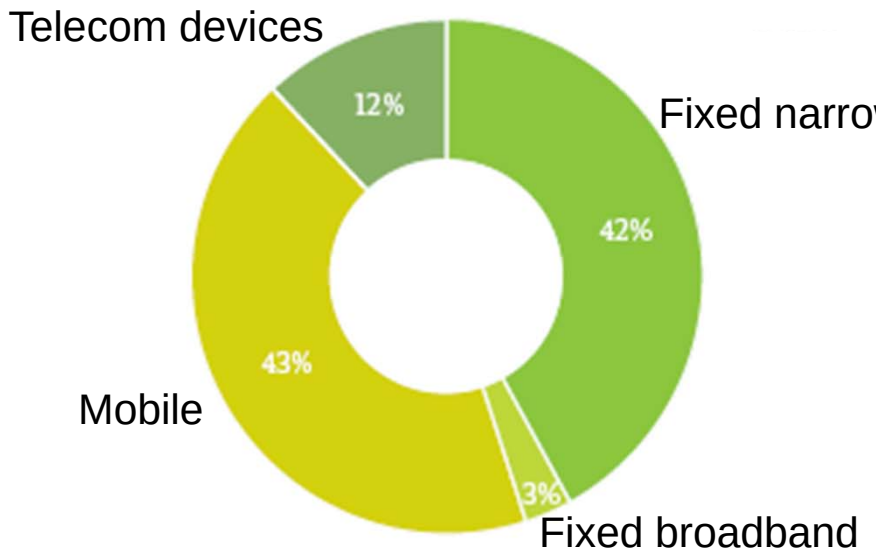
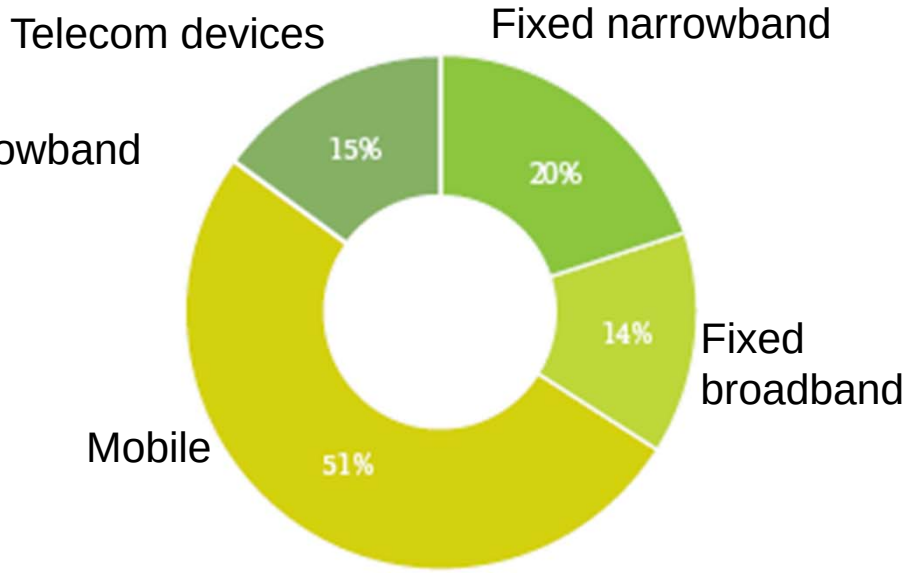
Energy-Efficient Wireless Nets – Something Important?

2002: 100% = 151Mt CO_2 emissions



2020: 100% = 349 Mt CO_2 emissions

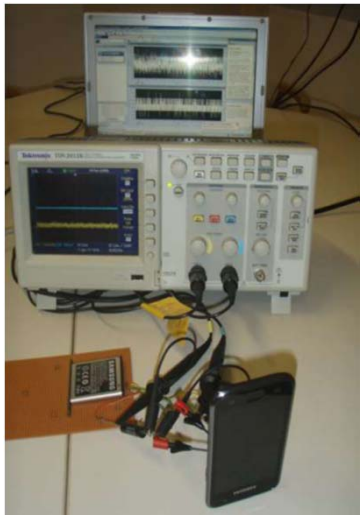


Source: SMART 2020: Enabling the low carbon economy in the information age.

EE Wireless Networks – Something Special?

Wireless networking

- Interferences – adaptable
- Energy efficiency is a traditional design issue



Measurement

- Wireless infrastructure (e.g., WLAN access points)
  - Wattmeter
- (Battery powered) mobile clients
  - Oscilloscope, Monsoon power meter, device API, etc.
- Distributed power measurements (e.g., WSNs)

Modeling, calibrating

- General models impaired by mobile device, sensor node particularities

Important Questions …

Characteristics of wireless networks?

- Use cases, energy footprint

Potential **methods** to improve EE in wireless networks?

- Resource consolidation, avoiding over-provisioning (redundancy, consumption proportional with load), accepting under-provisioning
- Making algorithms clever/smart/strategic – adaptable

Offloading, ad-hoc networks? – Are delay tolerant and **opportunistic networks** **feasible**?

Wireless Networks

Cellular networks 3G/LTE, **WiMAX IEEE 802.16**

- Base stations plus wired backbone

Wireless LANs IEEE 802.11a/g/n

- Infrastructure provided by access points
- Ad-hoc

Personal Area Networks, Wireless Sensor Networks

- Bluetooth, ZigBee

Source of pic: wikipedia

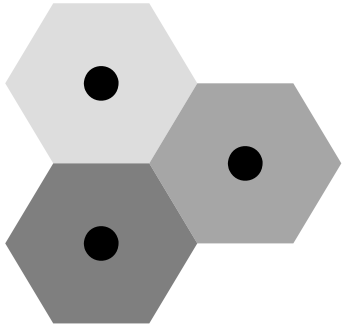
Cellular Networks

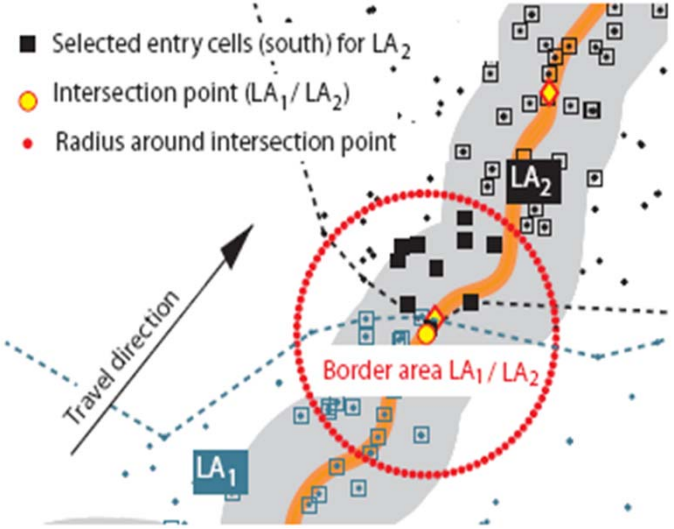
Traditional: provision of 24/7 availability

- Telephony - and data transmission
- Ubiquitous mobility sensor

Mobile terminal

Base transceiver station:
hosting transceivers





[A. Janecek, D. Valerio, K.A. Hummel, F. Riciato, H. Hlavacs. Cellular Data Meet Vehicular Traffic Theory: Location Area Updates and Cell Transitions for Travel Time Estimation. Ubicomp 2012]

Cellular Networks – Energy Consumption

Energy consumption

- [EARTH project: https://www.ict-earth.eu/, Trend …]
- Major factor: radio access network – transceiver

Energy footprint (orders of magnitude)

- Mobile device: ~0.1 Watt
- **Base station: ~1kWatt**, network controller (BSC, RNC): ~1kWatt, core (incl. servers): ~10 kWatt

[M. Gruber et al. EARTH -Energy Aware Radio and Network Technologies. PIMRC 2009]

Wireless LANs

IEEE 802.11a/g/n/…

- 2.4 GHz / 5 GHz band

Infrastructure mode (campus wide networks)

Ad hoc and opportunistic mode

- Disaster situations, local exchange
- Additional networking option

www.swarmix.org

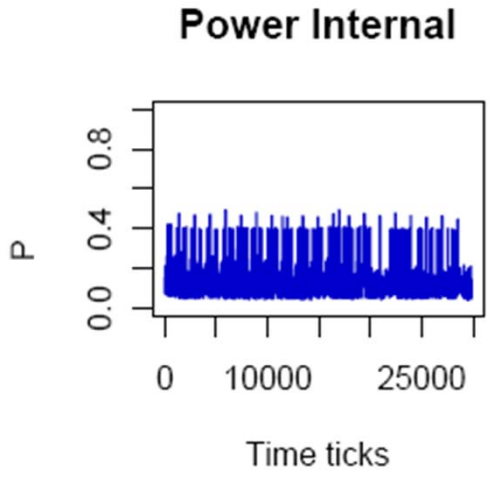
Wireless LANs – Energy Consumption

Energy consumption

- Beaconing (AP), scanning and roaming (mobile client)
- MAC – scheduling
- Data transfer

Energy footprint (orders of magnitude)

- Access Points: 1 Watt
- Ad-hoc: IDLE ~ 1 Watt, Tx/Rx: ~1.5 Watt
- Mobile smart phones (clients): IDLE ~0.1 Watt



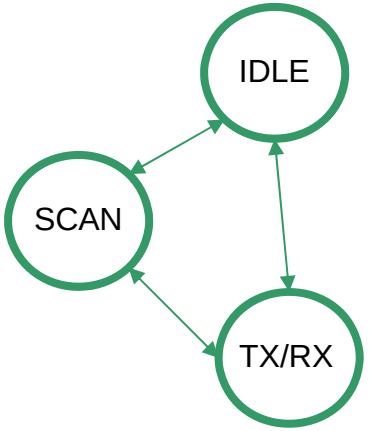
Mobile Device Models

NS-3 (*DeviceEnergyModel*)

- IDLE, CCA_BUSY, RX, TX, SWITCHING
- Alternative: Off, sleep, listen, receive, transmit*)

Energy ranges (vary between mobile devices)

- IDLE: 0.1-0.4 Watt
- SCAN (offset to IDLE): 0.5-1 Watt
- TX/RX (offset to IDLE): 0.4-1.6 Watt



*) [M. Ergen and P. Varaiya. Decomposition of Energy Consumption in IEEE 802.11, ICC'07]

[Aaron Carroll and Gernot Heiser. 2010. An analysis of power consumption in a smartphone. In *2010 USENIX conference on USENIX annual technical conference* (USENIXATC'10)]

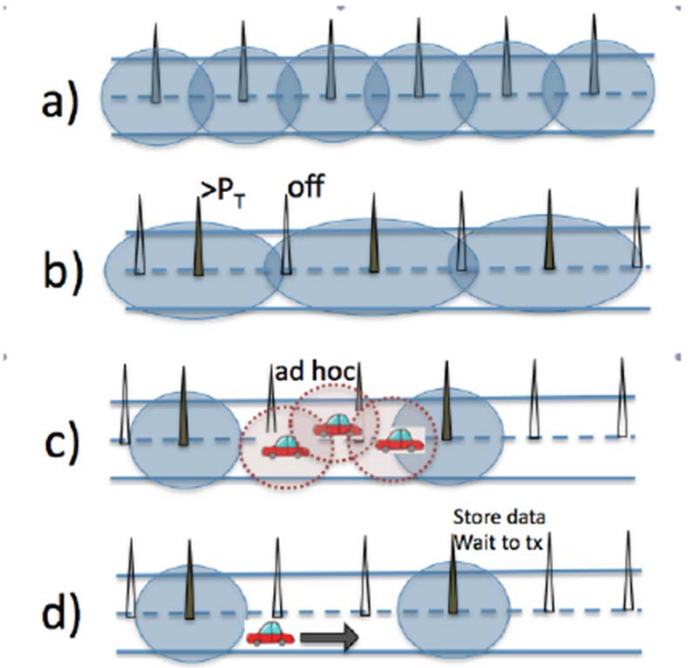
Energy-efficiency in Wireless Networks

Switch-off equipment

- Idle / sleeping mode

How? Basic methods

- Avoid overprovisioning, adjusting transmission range (b)
- Use ad-hoc communication (c)
- **Leveraging mobiles devices DTN (d)**



- EE components: short duty cycles, rate adaptation, transceivers, adaptive antennas, cooperative scheduling, enhanced cooling, etc.

[Y.Al-Hazmi, K.A. Hummel, M. Meo, H. Meyer, H.de Meer, and D. Remondo. Energy-efficient Wireless Mesh Infrastructures. IEEE Network Magazine, 25(2):32-38, 2011]

… More Sophistication

Multiple networks → hybrid networks

Trade-off – accepting lower quality (QoS, QoE)

- Videos encoded at lower bitrates, Web access latencies

Prediction (mobility, access)*)

- Explore idle mode due to forecasting and regularities

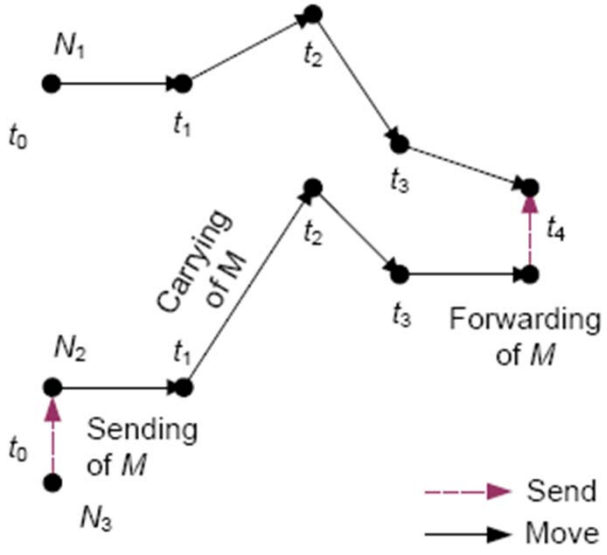
EE routing

- Distributed solution

*) [J. Gossa, A. Janecek, K.A. Hummel, W.N. Gansterer, J.-M. Pierson. Proactive Replica Placement Using Mobility Prediction. in Proceedings: DMCAC 2008 (in conj. with MDM 2008), Beijing, China]

Opportunistic Networking

- Delay tolerant network
- Use mobility of nodes to connect relays



WLAN-Opp

Enabling technology developed at ETH Zurich due to

- Sometimes: absence of infrastructure or no “open” APs
- Modern smartphones do not allow ad-hoc connectivity (un-rooted, automatic)

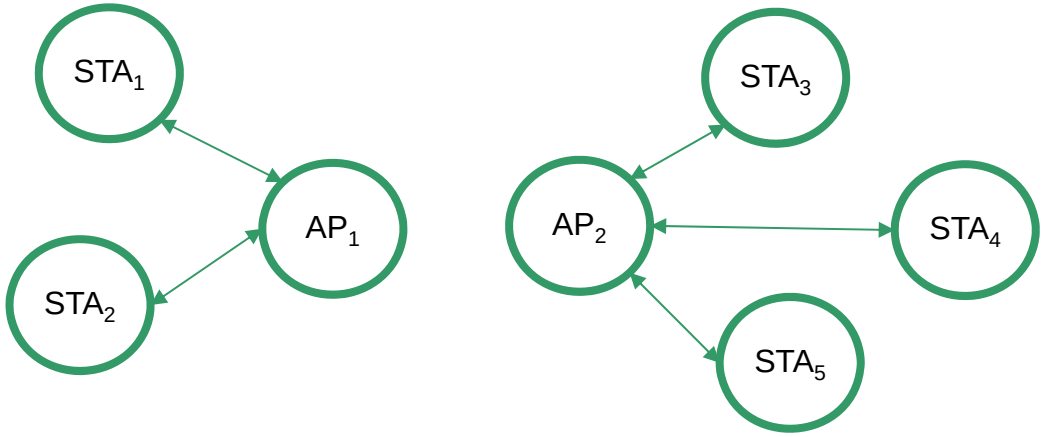
Solution: Use tethering mode

- Some stations changing into WLAN-Opp AP mode
  - Provide beaconing and relaying
- Other stations connect to infrastructure or WLAN-Opp APs (STA mode)

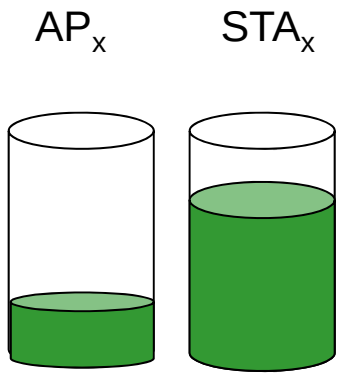
[Sacha Trifunovic, Bernhard Distl, Dominik Schatzmann, and Franck Legendre. 2011. WiFi-Opp: ad-hoc-less opportunistic networking. 6th ACM Workshop on Challenged Networks (CHANTS '11)]

Two Algorithmic Problems

Clustering



Battery

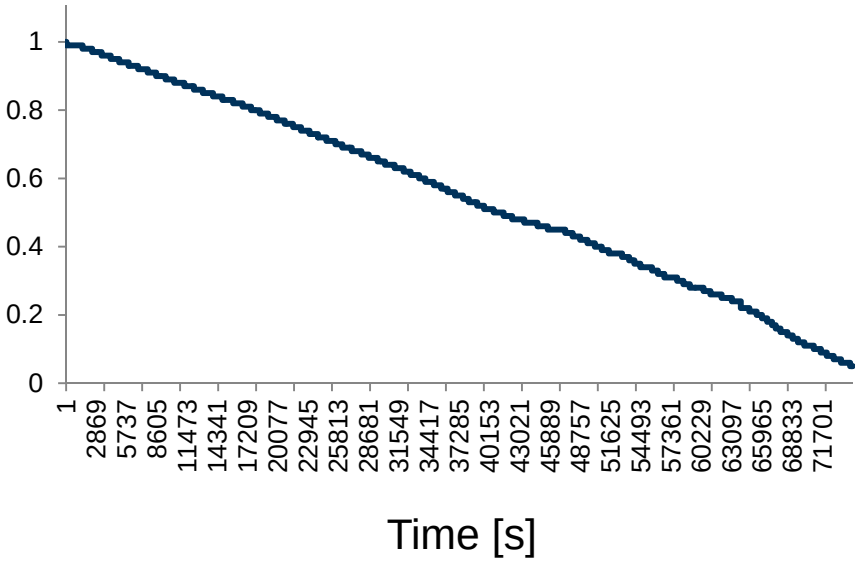


STA vs. AP Mode only – WLAN-Opp

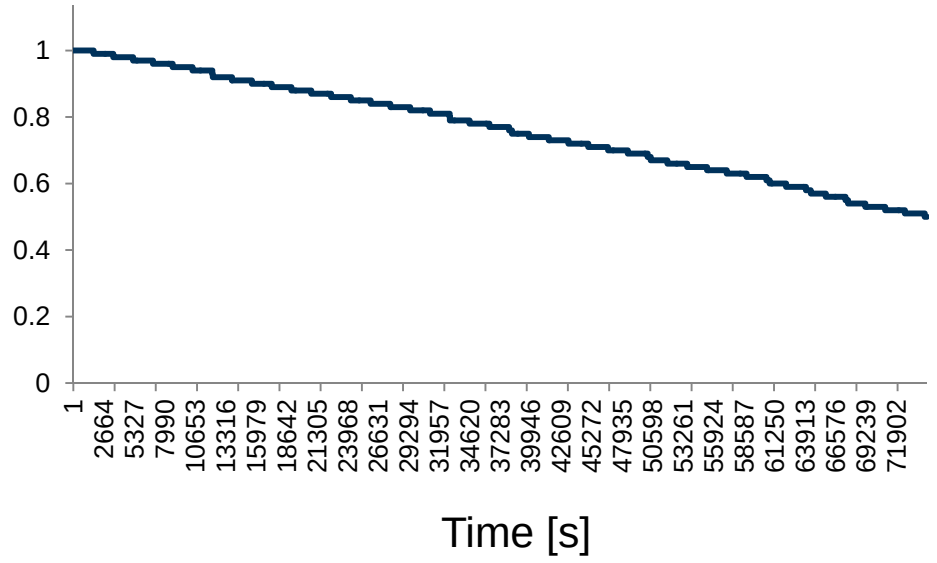
Example: 1 AP only, two STA only nodes (Samsung Galaxy)

- After 20h 42’ 44”: AP (5%), STA (50%)

AP – BATTERY Level



STA – BATTERY Level



Solving the Algorithmic Problems

Change between **major states:** AP, STA, IDLE

- Stations switch
- Controlled via timers

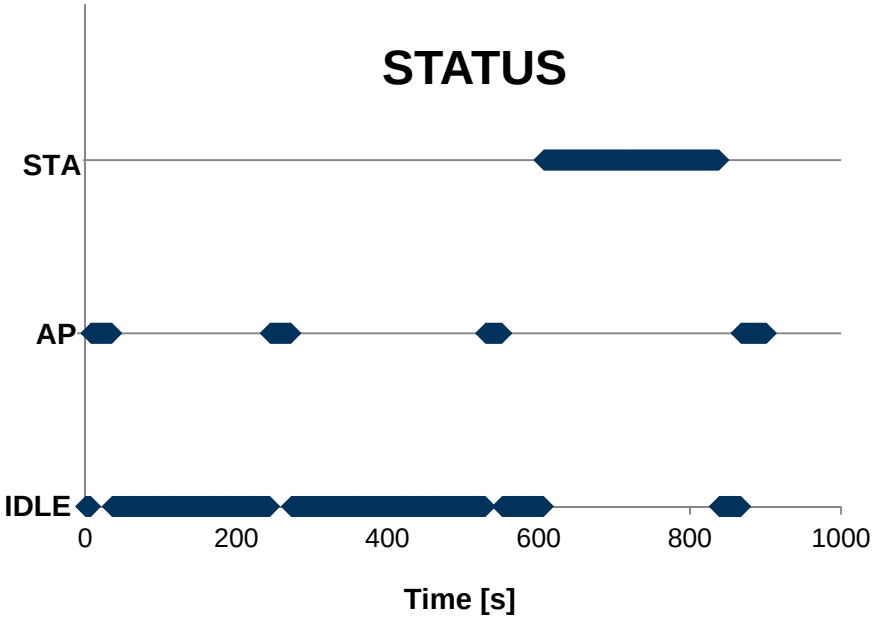
→ APs – time-limited service provisioning

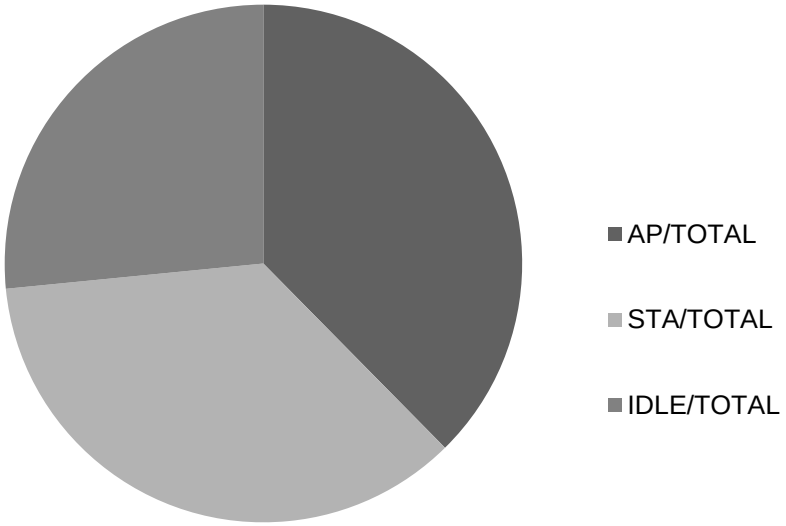
→ STAs – switch AP (scan for new) from time to time

Battery Depletion Measurements – WLAN-Opp

Experiment: 10 nodes switching, similar results (18h 23')

- Mean fraction of time in mode AP(40%), STA(35%), IDLE(25%)
- Mean depletion: 45%





Thank you!

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