ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Ασύρματα Δίκτυα και Κινητοί Υπολογισμοί

Μαρία Παπαδοπούλη

Τμήμα Επιστήμης Υπολογιστών

Πανεπιστήμιο Κρήτης

Χρηματοδότηση

- Το παρόν εκπαιδευτικό υλικό έχει αναπτυχθεί στα πλαίσια του εκπαιδευτικού έργου του διδάσκοντα.
- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Κρήτης**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
- Το έργο υλοποιείται στο πλαίσιο του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» και συγχρηματοδοτείται από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο) και από εθνικούς πόρους.

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επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ

ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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  - που δεν περιλαμβάνει άμεσο ή έμμεσο οικονομικό όφελος από την χρήση του έργου, για το διανομέα του έργου και αδειοδόχο
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- Ο δικαιούχος μπορεί να παρέχει στον αδειοδόχο ξεχωριστή άδεια να χρησιμοποιεί το έργο για εμπορική χρήση, εφόσον αυτό του ζητηθεί.

Wireless network topologies can be controlled by

- **Data rate**
- **Channel allocation: different devices communicate at different channels**

  In some cases, there is a channel dedicated for the control (management) and message exchange

- **Transmission power (power control)**
- **Carrier sense threshold**
- **Directional antennas**
- **Cognitive intelligent radios & software defined radios**
- **Node placement**
- **Different network architectures/deployments (e.g., mesh networks, infrastructure-based, ad hoc)**

IEEE 802.11 Rate Adaptation

- The 802.11 a/b/g/n standards allow the use of multiple transmission rates
  - 802.11b, 4 rate options (1,2,5.5,11Mbps)
  - 802.11a, 8 rate options (6,9,12,18,24,36,48,54 Mbps)
  - 802.11g, 12 rate options (11a set + 11b set)

- The method to select the transmission rate in real time is called “Rate Adaptation”

- Rate adaptation is important yet *unspecified* by the 802.11 standards

IEEE 802.11 Rate Adaptation

- IEEE802.11b

  11, 5.5, 2, 1 Mbps
- IEEE802.11a

  6, 9, 12, 18, 24, 36, 48, 54 Mbps
- IEEE802.11g

  802.11b rates + 802.11a rates
- Most of existing wireless radios are able to support multiple transmission rates by a combination of different modulation and coding rates

IEEE802.11 Bitrate Adaptation

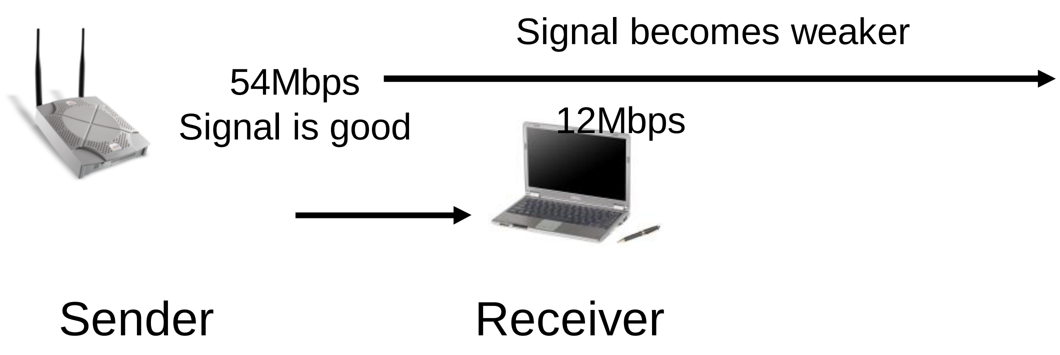
- When a sender **misses 2 consecutive ACK**

☞ ***Drops*** sending rate by changing modulation or channel coding method

- When **10 ACKs are received successfully**

☞ Transmission rate is ***upgraded*** to the next higher data rate

Rate adaptation example



- Ideally, the transmission rate should be adjusted according to the channel condition

Throughput Degradation due to Rate Adaptation

Example

- Some hosts may be far way from their AP so that the quality of their radio transmission is low
- Current IEEE802.11 clients degrade the bit rate from the nominal **11Mbps to 5.5, 2, 1Mbps**

👎 Such degradation also penalizes fast hosts and privileges the slow one

Throughput Degradation due to Rate Adaptation - Intuition

In 802.11b: every node gets the *same chance* to access the network

- When a node grabs the medium, it can send the **same sized packet** (**regardless of its rate**)

☞ So fast and slow senders will both experience low throughput

CSMA/CA:

- Basic channel access method guarantees the **long-term channel access probability to be equal among all hosts**
- When one host captures the channel for a long time, because its bit rate is low, it penalizes other hosts that use the higher rate

Example

- **N nodes transmitting at 11 Mb/s**
- **<u>1 node</u> transmitting at 1 Mb/s**

👎 All the node **only transmit at a bitrate < 1 Mbps !**

Performance Degradation due to Bit Rate Adaptation of the IEEE802.11

- The throughput is **not** related to the **sending rate** of a node because
  - **All nodes have the same transmission time** &**frame size**

☞ Thus fast hosts see their throughput decreases roughly to the order of magnitude of the slow host's throughput

- The fair access to the channel provided by CSMA/CA causes
  - Slow host transmitting at 1Mbps to capture the channel eleven times longer than hosts emitting at 11Mbps

☞ This degrades the overall performance perceived by the users in the considered cell

Possible Improvements

☞ Keep good aspects of DCF

- No explicit information exchange
- Backoff process

Proposed modifications

- No exponential backoff procedure
- Make hosts use similar values of CW
- **Adapt CW to varying traffic conditions**

  ☞ More hosts, bigger CW; less hosts smaller CW

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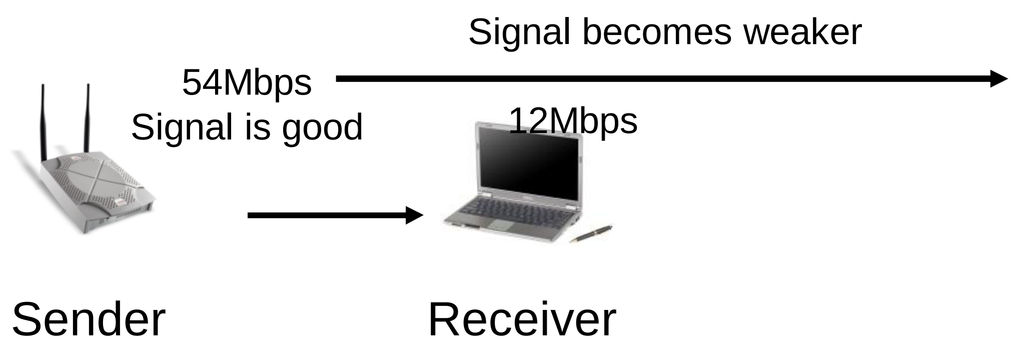
Rate adaptation example



- Ideally, the transmission rate should be adjusted according to the channel condition

Importance of rate adaptation

Rate adaptation plays a critical role to the throughput performance

– Rate too high → loss ratio increases → throughput decreases

– Rate too low → under-utilize the capacity → throughput decreases

Impact of Rate Adaptation

☞ Rate adaptation plays a critical role to the throughput performance:

Rate too high → loss ratio ↑ → **throughput** ↓

Rate too low → capacity utilization ↓ → **throughput** ↓

Client AP selection

- Select the appropriate AP based on various criteria to **optimize the service**

For that the client needs to

- Perform probing/measurements to estimate various criteria

Measuring Network Load

- **Dynamic nature of traffic**
  - Dynamic **number of clients** & **bandwidth demand**
- Channel Utilization
- Transmit Queue Length
  - Easy to measure
  - Highly variable
- MAC/Packet Delay
  - Transmit queue and channel contention tim
  - Most attractive – very steady readings

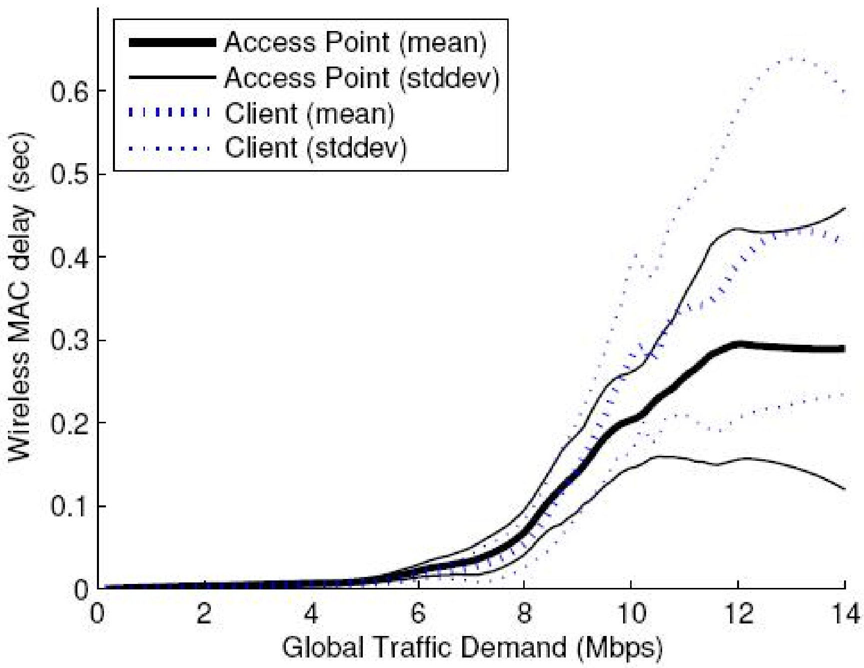


Figure 5. MAC delay versus traffic load

Measuring network load – tuning parameters

- Load average

    Calculated using a **moving average** to **negate small changes**

- Shrinking the **averaging interval**
    - Causes the system to converge on the maximum global throughput quickly
    - **excessive channel switching**
- Increasing the averaging interval
    - Slower convergence
    - Less time wasted switching channels

Heterogeneous wireless networks

- Crowded ISM band

e.g., coexistence of wireless LANs and wireless sensor networks

IEEE802.15.4 wireless sensor network coexisting with an IEEE 802.11 WLAN

- The transmission power of WLAN terminals is orders of magnitude higher than that of co-existing WSN
- The WLAN terminals are “blind” towards WSN transmissions

  WSN transmissions: **lower power, narrow band**
- WLAN causes **harmful interference in the WSN**, while itself remains unaffected from the WSN interferers
- WSN nodes can avoid WLAN interference, and thus, costly packet retransmissions, **only if they are armed with cognitive capabilities**

  i.e., optimize their transmission parameters and communication protocols accordingly
- In the case of WLAN interferers, the sensors force the WLAN to backoff by sending short, high power jamming signals

Wireless channel exhibits rich channel dynamics in practical scenarios

- Random channel error
- Mobility-induced change
- Collisions induced by
  - Hidden-terminals
  - Multiple contending clients

Power & energy models

Power consumption P of a device is expressed:

$$P = \Sigma_i(\beta_i \times x_i) + P_{base} + P_\epsilon$$

Here, x_i represents the vector of usage measurement for hardware component i and β_i the power coefficient for component i. Also, P_{base} is the base power consumption, and P_ϵ is a noise term that cannot be estimated by the model. Then, the total energy consumption E of a smartphone is expressed as:

$$E = \sum_j E^j + (P_{base} + P_\epsilon) \cdot D, \text{ where}$$

$$E^j = \sum_i(\beta_i \times x_i^j) \cdot d_i^j \qquad (2)$$

Here, D is the device's power-up duration. E^j is the energy consumed by process j. E^j is expressed with β_i, x_i^j, and d_i^j, where x_i^j and d_i^j represent the usage vector and active duration of hardware component i accessed by process j, respectively. Note that the accuracy of E^j is influenced by β_i, x_i^j, and d_i^j. To estimate the energy consumption of smartphone applications, it is essential to obtain accurate values of β, x, and d in an effective

x_i: usage vector
d_i: active duration
Pbase: base power consumptions

Table 1: Power model for smartphone components

Component	Model
CPU	$P^{CPU} = \beta_{freq}^{CPU} \times u + \beta_{freq}^{idle}$ u: utilization, $0 \leq u \leq 100$ $freq$: frequency index, $freq = 0,1,2 \cdots, n$
LCD	$P^{LCD} = \beta_b^{LCD}$ b: brightness level, $\mathrm{MIN}(level) \leq b \leq \mathrm{MAX}(level)$
WiFi	$P^{WIFI} = \begin{cases} \beta_l^{WIFI} \times p + \beta_l^{base}, & if\ p \leq t \\ \beta_h^{WIFI} \times p + \beta_h^{base}, & if\ p > t \end{cases}$ p: packet rate, t: threshold
cellular(3G)	$P^{3G} = \begin{cases} \beta_{IDLE}^{3G}, & if\ RRC\ state\ is\ IDLE \\ \beta_{FACH}^{3G}, & if\ RRC\ state\ is\ FACH \\ \beta_{DCH}^{3G}, & if\ RRC\ state\ is\ DCH \end{cases}$
GPS	$P^{GPS} = \beta_{on}^{GPS},\ if\ GPS\ is\ on$

FACH: forward access channel
Reaches this state when data communication starts

IDLE: when there is no data being sent or receive
DCH: while data is being sent or received

A discussion on Energy Management with IEEE 802.11n

Reference: Snooze: Energy Management in 802.11n WLANs

by Ki-Young Jang, Shuai Hao, Anmol Sheth, Ramesh Govindan

The purpose of **IEEE 802.11n** is to improve network throughput over the previous standards IEEE 802.11a and 802.11g

with a significant increase in the maximum net data rate from **54 Mbit/s to 600 Mbit/s**.

IEEE 802.11n features

- Multiple-input multiple-output(MIMO)
- Frame aggregation on MAC layer
- 40 MHz channels to the physical layer
- Security improvements

MIMO uses multiple antennas to coherently resolve more information than possible using a single antenna

IEEE 802.11n energy usage

- Has additional power states
- **Beyond a low-power sleepmode**, it offers the possibility of **selectively disabling one or more RF-front ends** (*RF-chains*) associated with its antennas, thereby saving energy
- **Micro-sleeping***:* enables the IEEE 802.11n NIC to be put into low-power sleep state for small intervals of time (often a few milliseconds)

- **Antenna configuration management** which dynamically adapts the number of powered RF-chains.

Key idea: Antenna configuration should be *adaptive* based on traffic demand and link quality.

- **Shapes traffic** to create sleep opportunities
- Minimal impact on traffic
- Minimizes the number of active clients
- **Manages antenna configurations**
- Minimizes antennas needed

General advice: An approach for systems research

1. Hypothesize about requirements based on potential applications
2. Explore design space based on these requirements
3. Develop hardware platform for experimentation
4. Build test applications on top of hardware platform
5. Evaluate performance characteristics of applications
6. GOTO step 1 (hopefully you'll come up with a better set of requirements)

Autonomous Networking Systems

- Operate with ***minimum human intervention***
- Capable of
  - Detecting impending **violations of the service requirements**
  - ***Reconfiguring*** themselves
  - **Isolating failed or malicious components**

Issues in Wireless Networks

- Performance

  throughput, delay, jitter, packet losses, “user satisfaction” (i.e., QoE)

- Connectivity

  roaming, coverage, capacity planning

- Security

  various types of attacks, vulnerabilities, privacy issues

Issues in Wireless Communications

☞ Deal with fading and interference

• Increase the ***reliability*** of the air interface
  increase the probability of a successful transmission

• Increase the ***spectral efficiency***

Wireless Network – Performance Improvement

Parameters for Control

- Data rate
- Channel
- Network interfaces & overlay networks
- Transmission power
- Carrier sense threshold
- Directional antennas, cognitive intelligent radios, software-defined radios
- Node placement
- Architectures
- MAC protocols
- Markets, coallitions among operators, various services

Mechanisms

- Dynamic adaptation
  Online, on-the-fly
- Capacity planning
  Proactive, offline

Increasing capacity

- **Efficient spectrum utilization** issue of primary importance

- Increase capacity and mitigate impairments caused by
  - **Fading, delay spread co-channel interference**
  - **Use multiple-antenna systems**

- At the physical layer, advanced radio technologies, such as
  - Physical layer techniques (e.g., OFDM, and for small distances UWB)
  - **reconfigurable** and **frequency-agile** radios
  - **multi-channel** and **multi-radio** systems
  - **directional** and **smart antennas (e.g., multiple antenna)**
  - Antenna diversity
- Need to be integrated with the MAC and routing protocols
- **New access paradigms & markets!**

Performance of Wireless Networks

Spectrum

- ***Limited*** wireless spectrum
- **Capacity limits** (Shannon theorem)
- Parts of the spectrum are ***underutilized***

The spectrum is a valuable resource

☞ Wireless networks are more vulnerable than the wired ones

- Large growth of applications & services with real-time constraints and demand of high bandwidth

Wireless Networks - Challenges

☞ Wireless networks are very ***complex***

- Have been used for many different purposes
- ***Non-deterministic*** nature of wireless networks due to
  - Exogenous parameters
  - Mobility
  - Radio propagation characteristics

  ☞ wireless channels can be **highly asymmetric and time varying**

Difficult to

- Capture their impact on its performance
- Monitor large-scale wireless networks
- Predict wireless demand

☹ Interaction of different layers & technologies creates many situations that ***cannot be foreseen during design & testing stages of technology development***

Spectrum Utilization (1/2)

- Studies have shown that there are frequency bands in the spectrum **largely unoccupied most of the time** while others are heavily used

☞ **Cognitive radios** have been proposed to **enable a device to access a spectrum band unoccupied by others at that location and time**

Spectrum Utilization (2/2)

- **Cognitive radio**: intelligent wireless communication system that is
  - **Aware** of the environment
  - **Adapt to changes** aiming to achieve:
    - ***reliable communication*** whenever needed
    - ***efficient utilization of the radio spectrum***

Their commercialization has not yet been fully realized

- Most of them still in research & development phases
- Cost, complexity, and compatibility issues

Improvement at MAC layer

- To achieve higher throughput and energy-efficient access, devices may use **multiple channels** instead of only one fixed channel

Depending on the number of radios & transceivers, wireless network interfaces can be classified:

1. **Single-radio MAC**
   - **Multi-channel single-transceiver**
   - **Multi-channel multi-transceiver**

2. **Multi-radio MAC**

Multiple Radio/Transceivers

- ***Multi-channel single-transceiver*** MAC
  - ***One tranceiver*** available at network device
  - *Only one* channel **active** at a time in each device
- ***Multi-channel multi-transceiver*** MAC
  - Network device with **multiple RF front-end chips & baseband processing modules** to support **several simultaneous channels**
  - Single MAC layer

  controls & coordinates the access to multiple channels
- ***Multi-radio*** MAC
  - network device with multiple radios

    each with **its own MAC & physical layer**

Spectrum Division

Non-interfering disjoint channels using different techniques:

- ***Frequency division***

  Spectrum is divided into disjoint frequency bands

- ***Time division***

  channel usage is allocated into time slots

- ***Code division***

  Different users are modulated by spreading codes

- ***Space division***
  - Users can access the channel at
    - the same time
    - the same frequency

    by exploiting the spatial separation of the individual user

- ***Multibeam (directional) antennas***

  used to separate radio signals by pointing them along different directions

Dynamic Adaptation

- ***Monitor*** the environment
- Relate **low-level** information about resource availability with network conditions to higher-level functional or performance specifications

- ***Select*** the appropriate
  - **Network interface**
  - **Channel**
  - **AP**
  - **Power transmission**
  - **Bitrate**

Channel Switching

- Fast discovery of devices across channels
- Fairness across active flows & participants
- Accurate measurements of varying channel conditions
- Infrequent changes in the connectivity between devices

Channel or Network Selection

- Static or dynamic
- Based on various criteria
  - Traffic demand
  - Channel quality
  - Bandwidth and round-trip-time estimations
  - Application requirements
  - Registration cost
  - Admission control

Challenges in Channel & Network Selection

☞ In order to be effective, channel/network selection require accurate estimation of channel conditions in the presence of dynamics caused by

– fading
– mobility
– hidden terminals

- This involves:
  - distributed and collaborative monitoring
  - analysis of the collected measurements

- Their realization in an **energy-efficient on-the-fly** manner opens up several research challenges

Capacity Planning Objectives

- Provide sufficient coverage and satisfy demand
  - consider the ***spatio-temporal evolution*** of the demand

- Typical objectives:
  - **minimization of *interference***
  - **maximization** of ***coverage area & overall signal quality***
  - **minimization of *number of APs for* providing sufficient coverage**

☞ While **over-provisioning** in wired networks is acceptable,
it can become problematic in wireless domain

Capacity planning (1/2)

- Unlike device adaptation that takes place dynamically, ***capacity planning determines proactively*** the
  - ***AP placement***
  - ***Configuration (frequency, transmission power, antenna orientation)***
  - ***AP administration***

On power transmission

☞ trade-off between **energy conservation & network connectivity**

Capacity Planning: Power Control

- **Reducing transmission power, lowers the interference**
  – Reduces
    - **Number of collisions**
    - **Packet retransimissions due to interference**
  – Results in a
    - **Smaller number of communication links**
    - **Lower connectivity**

☞ trade-off between **energy conservation & network connectivity**

Power Control

- Integral component of capacity planning

- Aims to control

  spectrum spatial reuse, ***connectivity***, and ***interference***

- Adjust the transmit power of devices, such that their SINR meets a certain threshold required for an acceptable performance

Connectivity Problems

- Reflect **lack of sufficient wireless coverage**

- An end user may observe **degraded performance**
  - e.g., **low throughput** or **high latency**

due to:

  - Wired or wireless parts of the network
  - Congestion in different networking components
  - Slow servers

Roaming (1/2)

☞Handoff between APs and across subnets in wireless LANs can consume from **one to multiple seconds** as associations and bindings at various layers need to be re-established

Examples of sources of delay include

- **Acquiring new IP addresses**, with duplicate address detection
- **Re-establishing associations**
- **Discovering possible APs**
  - Without scanning the whole frequency range

Roaming (2/2)

The **scanning** in a handoff

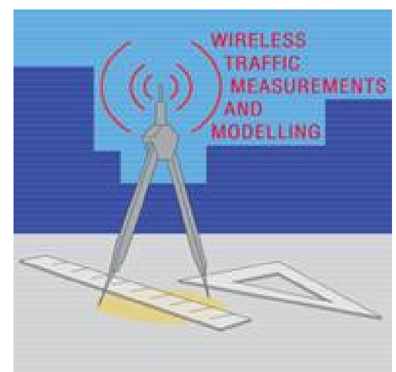
- Primary contributor to the overall handoff latency
- Can affect the **quality of service for many applications**
- Can be 250ms or more
- Far longer than what can be tolerated by highly interactive applications (i.e. voice telephony)

Security Issues

- Involve the **presence of rogue APs** & **malicious clients**
- In mobile wireless networks, it is easier to
  - disseminate worms, viruses, false information
  - eavesdrop
  - deploy rogue or malicious software or hardware
  - attack, or behave in a selfish or malicious manner
- Attacks may
  - occur **@ different layers** aiming to exhaust the resources
  - promise **falsely to relay packets**
  - **not respond to requests for service**

Monitoring

- Depending on type of conditions that need to be measured, monitoring needs to be performed at
  - Certain layers
  - **Spatio-temporal** granularities
- Monitoring tools
  - Are **not** without flaws
  - Several issues arise when they are used in parallel for thousands devices of different types & manufacturers:
    - ***Fine-grain* data sampling**
    - Time ***synchronization***
    - ***Incomplete* information**
    - Data ***consistency***



Issues in Data Collection

1. Synchronization

- Skew of the clocks
  - affected via various external parameters

  e.g., temperature, voltage, electromagnetic interference
- Synchronization can be done using Network Time Protocol (NTP) & Precision Time Protocol (PTP)

2. Data Consistency

Differences in how various monitoring tools record the data

3. Incomplete information

Monitoring tools fail to capture different parameters due to misconfigurations, failures, limited functionality

Challenges in Monitoring (1/2)

- **Identification** of the dominant parameters through
  - sensitivity analysis studies
- **Strategic placement** of monitors at
  - Routers
  - APs, clients, and other devices
- **Automation** of the monitoring process to reduce human intervention in managing the
    - Monitors
    - Collecting data

Challenges in Monitoring (2/2)

- Aggregation of data collected from distributed monitors to improve the accuracy while maintaining low overhead in terms of
  - Communication
  - Energy

- **Cross-layer measurements**, collected data spanning from the physical layer up to the application layer, are required

Τέλος Ενότητας

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης