

The background of the slide features a dark blue field filled with numerous fiber optic cables. These cables are oriented vertically, with their ends glowing in various colors including blue, green, red, and white. In the upper portion of the image, there is a dense collection of out-of-focus light points, creating a bokeh effect with soft, circular highlights in shades of blue, green, and white.

# P2P IoT

gd

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# P2P and IoT Systems

## 1 Introduction

### ARPANET

*The Advanced Research Projects Agency Network (ARPANET) was an early packet switching network and the first network to implement the protocol suite TCP/IP.*

#### • P2P SYSTEM

The initial internet was a fast reconfigurable hop based system.

#### • CLIENT SERVER

Later reconfigured with **IP routing system**. **APP LAYER End2End**

### OVERLAY NETWORK

*An overlay network is a computer network that is built on **top of another network**.*

**UNDERLAY OVERLAY**

#### • CLIENT

have an **active role and initiate a communication** session

**HW:** Consumer device

**THIN vs FAT**

#### • SERVER

have a **passive role and respond** to their clients.

**HW:** Powerful.

**CONCURRENT** (Thread-per-client or pool) **vs ITERATIVE**

#### • 3 LAYERS

Presentation, Application and Database.

**1-TIER:** Everything in one. **Mainframes**

**2-TIER:** Client-server in which we **distribute resources**.

### P2P SYSTEMS

*In the P2P model, all end systems have **equivalent capabilities and responsibilities** and either party can initiate a communication session*

#### 1. PROVIDER & REQUESTOR

#### 2. SYMMETRIC BANDWIDTH

#### 3. SAME SOFTWARE

#### 4. PEER

Servents providing and requesting resources

#### 1. POOR SECURITY

#### 2. NO CENTRALISED CONTROL

#### 3. PERFORMANCE PROBLEMS



## 2 Evolution of P2P

### WWW

The World Wide Web is an **information space** where documents and other web resources are identified by Uniform Resource Locators (URLs), interlinked by hypertext links, and can be accessed via the Internet.

#### INTERNET FOR EVERYONE

- UBIQUITOUS
- ASYMMETRICAL  
Low rate links in up, huge **links in download**
- FIREWALL
- NAT
- DYNAMICAL IP ASSIGNMENT
- PROBLEMS BUT FOR WWW

### P2P SYSTEM: NAPSTER

#### • SEPARATION OF SIGNALING AND DATA

1. CENTRAL INDEX SERVER  
Lists all the data. **Single point of failure: NAPSTER was shut down.**
2. HANDSHAKE  
Central server exchange **information to and from the peers.**

1. SCALABILITY OF CENTRAL SERVER
2. FIREWALL  
Alternate download, ask **uploader to connect to downloader**
3. RELIABILITY  
dDos attack, legal prosecution
4. SECURITY  
mp3 authenticity and protocol **encryptions.**

### GNUTELLA VO.4

Gnutella is a large peer-to-peer network. It was the first **decentralized peer-to-peer network** of its kind, leading to other, later networks adopting the model

#### PING PONG QUERY QUERY\_HIT

- A. DECENTRALISATION
- B. SEARCHING STRATEGY

**Query Flooding:** a simple computer network routing algorithm in which every incoming packet is **sent through every outgoing link** except the one it arrived on.

**AVOID REDUNDANT:** TTL and ID

1. OPEN SOURCE
2. AUTONOMOUS, HARD TO SHUT DOWN

1. SIGNALLING TRAFFIC
2. LOW PERFORMANCE FOR LOW SPEEDS
3. NO-FULLY DECENTRALISE

### GNUTELLA VO.6

#### A. ULTRAPEERS

Supernode is any node that also serves as **one of that network's relayers and proxy servers**, handling data flow and connections for other users.

1. LOWER SIGNALING TRAFFIC  
Ultra-peers select what to forward.

## GNUTELLA 2

### A. HUBS: ROUTING TABLE

#### BOOTSTRAPPING

A bootstrapping in an overlay network **provides initial configuration information** to newly joining nodes.

#### FAST TRACK

FastTrack is a peer-to-peer protocol that was used by the Kazaa, Grokster, iMesh, and Morpheus file sharing programs. FastTrack was the **most popular file sharing network in 2003**, and used mainly for the exchange of music mp3 files.

##### 1. BOOTSTRAPPING

##### 2. REPUTATION SYSTEM

Participation level in **terms of resources**

##### 1. ASYMMETRIC RESOURCES

#### EDONKEY

The eDonkey Network is a **decentralized, mostly server-based, peer-to-peer file sharing** network created in 2000

##### • SWARMING

Files are chunked into **smaller pieces** and are **distributed across the network, reducing the load on peers which have complete file.**



### 3 Searching for Resources

#### ALGORITHM FOR SEARCHING

System	Per Node State	Communication Overhead	Fuzzy Queries	No False Negatives	Robustness
Central Server	$O(n)$	$O(1)$	✓	✓	✗
Flooding Search	$O(1)$	$O(n^2)$	✓	✗	✓
Distributed Hash Tables	$O(\log n)$	$O(\log n)$	✗	✓	✓

#### DHT

A distributed hash table (DHT) is a class of a decentralized distributed system that provides a lookup service similar to a hash table

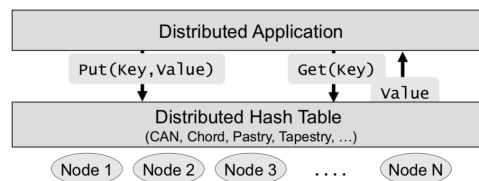
**FLEXIBLE RELIABLE SCALABLE**

#### • DATAS AND NODES

Every node is responsible for a certain amount of data.

#### • ADAPTATION FOR FAULTS

Faults and error must be **handled by the system**



#### 1. MAP CONTENT AND NODES

With an **hash function** assign a number in the **address space**.

#### 2. ASSIGN TO NODES

Addresses ranges are assigned to **single nodes** with a bit of **overlapping**.

#### 3. LOCATE THE DATA

Start by **bootstrapping and** asking nodes for **successor or predecessor**.

#### 4. FAILURE

Addresses are redistributed in **nearby nodes**.

## 4 Traffic management

### PROBLEM FOR ISP

From 2009 to 2014

- **UPLOAD BANDWIDTH COST**  
Asymmetry between **UP&DOWN**
- **64% INTERNET TRAFFIC IS P2P**
- **NO DISTRIBUTION**
- **HIGH-CONGESTED NETWORKS**

### OVER PROVISIONING

*Allocating additional bandwidth in Network planning and design dimensioning.*

- **DOESN'T ANSWER TO SHORT-TERM**
- **NOT UNIVERSAL SOLUTION**

### BLOCKING TRAFFIC

*Oratuce if blocking ports and network access point used by P2P systems.*

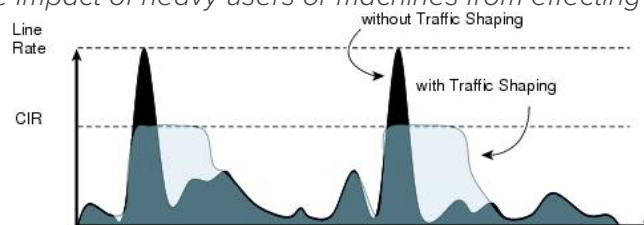
- **DYNAMIC PORTS**
- **DYNAMIC ADDRESSES**
- **LOWE TRAFFIC FOR ISP**
- **PACKET INSPECTING HARDWARE**

### BANDWIDTH CAPS

*Some Internet service providers have harsh restrictions on the amount of bandwidth you can use in a month, charging you extra if you go over your bandwidth cap.*

### TRAFFIC SHAPING

*Traffic shaping is the **manipulation and prioritization of network traffic** to reduce the impact of heavy users or machines from effecting other users.*



- **HIGH IMPLEMENTATION COSTS**  
**DPI** analyses header and pattern of first packets in the flow, thus requires advanced equipment and techniques.  
**PATTERN - BEHAVIOUR - STATISTICAL**
- **GOOD QOS**
- **NETWORK NEUTRALITY**
- **CONSTRUCTIVE APPROACH**
- **TRAFFIC PRIORITISATION**

### NETWORK CACHING

**Network caching** is the technique of keeping frequently accessed information in a location **close to the requester**.

### TRAFFIC LOCALISATION

**Traffic localisation** keep the traffic in smaller subnets avoiding unnecessary routing

- **SEGMENTATION**
- **AVOID UNNECESSARY TRAFFIC**



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## 5 BitTorrent protocol

### SYSTEM

1. TORRENT FILE
  2. WEB SERVER FOR TORRENT
  3. TRACKER
  4. ORIGINAL SEED
  5. APPLICATION
- 
1. UP & DOWN
  2. MULTISOURCE DOWNLOAD
  3. INTEGRITY CHECKS AS PIECE

### METADATA FILE

Torrent file is a computer file that contains **metadata** about files and folders to be distributed, and usually also a **list of the network locations of trackers**

1. SHA-1 PIECE HASES  
Content is **partitioned (256KB)** in smaller packet with calculated **hashes**
2. TORRENT HASH  
By putting the **TORRENT\_HASH** to zero.
3. PIECE LENGTH, FILE NAME, CONTENT-LENGTH, URL OF TRACKER

### BENCODING

Bencode (pronounced like B-encode) is the encoding used by the peer-to-peer file sharing system BitTorrent for storing and transmitting loosely structured data.

1. **STRING**. **Length**:string
2. **INTEGERS** **i**number**23**
3. **LISTS**. **L**element**e**
4. **DICTIONARIES**. **d**key:value**e**

### TRACKER

A BitTorrent tracker is a special type of server, one that assists in the communication between peers using the BitTorrent protocol.

- PRIVATE OR PUBLIC
- STORES PEERS INFORMATION
- STATISTICS
- SINGLE POINT OF FAILURES
- USED IN DIFFERENT PHASES  
Start, refresh, stop and completing.
- HTTP PROTOCOL  
160bit HASH to identify torrents in network

### DOWNLOAD PROTOCOL

- TCP
- EVERY PEER COMPLETE THE FILE
- SEED OR LEAVE

### PIECE SELECTION

1. PIECE AND SUBPIECE
2. SUB-PIECE  
All selected in one piece before **starting a new one**.
3. RANDOM SELECTION OF FIRST  
Until a piece is completed. Then **rarest first**
4. **END-GAME MODE**  
In order to **prevent the last pieces becoming unobtainable**, BitTorrent clients attempt to get the **last missing pieces from all of its peers**.

## CHOKING MECHANISM

Ensures that **nodes cooperate and eliminates** the free-rider problem.  
Temporary decision **not to upload**

A client chokes another client in several situations:

- A. SECOND CLIENT IS A SEED
- B. CLIENT UPLOADING AT MAX\_UPLOAD
- C. SECOND CLIENT IS BLACKLISTED

Characteristics:

- OPTIMISTIC UNCHOKING  
Random **unchoke one peer**.

## ANTI-SNUBBING

*Occasionally a peer will be choched by all peers which it was downloading from*

- OVER A MINUTE

A peer **is not uploadding, stop sending sub pieces**

- CHOKED BY EVERYONE

If choked by everyone, increase the **number of simultaneous optimistic unchokes to more than one**

## UPLOAD ONLY

*Upload to the ones which have best **upload rates***

## ENHANCEMENT PROPOSALS

*To overcome a single point of failure type of problem with one central tracker, **multitracker metadata extension** allows to define more than one tracker in the torrent file*

1. UDP TRACKER

Reduce the overhead in the tracker communication

2. PEX

can be used to **trade lists of other peers** after two peers are connected

3. UDP TRACKER

client will connect to **some bootstrap node** and from there receive a list of nodes which are also DHT enabled. **PEER BECOMES TRACKER**

## UDP TRACKER

- SIMPLE TRANSCODING
- FOUR MESSAGES

connect request, connect response, announce request, announce response

- PREVENT SPOOFFING

**connection\_id** have to match between trackers and client

- FAILURE'S RETRANSMISSIONS

If a packet is not received after **n seconds** have to be **retransmitted**.

## PEX

*leverages the knowledge of peers that a user is connected to by asking them for the addresses of peers that they are connected to*



## DHT PROTOCOL

A distributed hash table (DHT) is a class of a decentralized distributed system that provides a lookup service similar to a hash table: (key, value) pairs are stored in a DHT, and any participating node can efficiently retrieve the value associated with a given key.

**$O(\log n)$  to find a file**

- **BASED ON KADEMLIA - UDP**

- **PEER**

Client/server listening on a **TCP port**

- **NODE**

Client/server listening on a **UDP port**.

**NODE:ID** 160Bit for info hashes. Chosen random.

It returns **contact informations**, like **ip, port, client\_id, connectionid**

- **MESSAGE TYPES**

- **QUERY TYPES**

## CLUSTERING

To improve performances, hierarchical architecture group peers into cluster measuring **RTT - TTL**

1. **SPLIT**

2. **MERGE**

3. **PEER - LECHER - SUPER PEER**

Super peers maintains state information of all peers in a cluster.

4. **FUNDAMENTAL CLUSTER**

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## 6 P2P Streaming

### P2P STREAMING

Peer-to-Peer Assisted Streaming Solution refers to peer-to-peer (P2P) software applications designed to **redistribute video streams in real time** on a P2P network;

- **SCHEDULING OF CHUNKS**

- **PERFECTING QUALITY**

10-100s to perfect quality. Then **no improvements**

- **UDP PROTOCOL**

Because **TCP** has a RDP of 250ms (7 frames)

- **MESH TOPOLOGIES**

A mesh network is a network topology in which **each node relays data** for the network.

- **ASYMMETRICITY FOR U-D**

- **QUALITY DEGRADATION**

## COMPRESSION BASIC

**Lossless compression** is a class of data compression algorithms that allows the original data to be perfectly reconstructed from the compressed data. By contrast, **lossy compression** permits reconstruction only of an approximation of the original data, though this usually improves compression rates

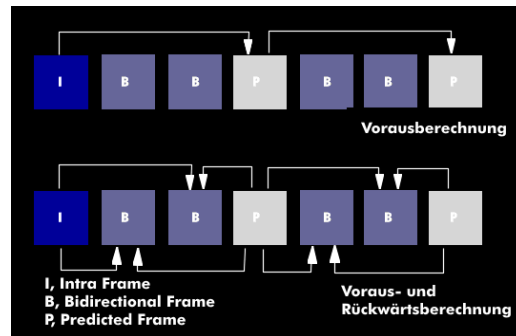
### 1. REMOVES FOLLOWING REDUNDANCIES

**Spatial, temporal and psycho-visual** (corners).

### 2. EXPLOIT THEM BY

**Predict pixel values** in space, time and loose some unnecessary info

### 3. TYPES OF FRAMES



**I-FRAMES.** Intracoded

**P-FRAMES.** Predicted. **Error propagation!**

**B-FRAMES.** Bidirectional predicted frames

## ASSESSING VIDEO QUALITY

Tests for assessing video + audio quality as to receive a media file quality rate.

### SERVICE INTEGRITY + AUDIOVISUAL QUALITY

### 1. SUBJECTIVE TESTS

Users are provided **MoS** grades for different media file (quality) and have to **rate them**.

### 2. OBJECTIVE TESTS

Simple pixel based metrics with **PSNR** and **MSE**.

### 3. COMPLEXIVE VALUE

Non-linear model combining audio and video quality, with **cross dependence between video and audio**.

## PROACTIVE WAYS

### 1. OVERLAY ARCHITECTURE

### 2. LAYERED CODING

### 3. MULTIPLE-DESCRIPTION CODING

### 4. TRAFIC LOCALISATION

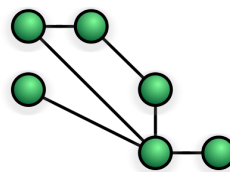
### 5. SCHEDULING

### 6. INCENTIVE MECHANISM

### 7. SERVER FARMS

## OVERLAY ARCHITECTURE

Meshes revolutionise the informations flow, making the system **more reliable**



## LAYERED CODING

Asynchronous Layered Coding protocol for content delivery in a reliable, massively scalable, **multiple-rate, and congestion-controlled manner**  
**PATH DIVERSITY**

- **N-LAYERS**

- **BASIC LAYER**

As user you are **subscribed to the basic one. ADDITIVE**

- **(n-1) LAYERS**

Provide **better quality** only for users who supports them.

## MULTIPLE DESCRIPTION CODING

Coding technique that fragments a single media stream into **n substreams**  
The packets of each description are **routed over multiple, (partially) disjoint paths.**

### PATH DIVERSITY

- **N-LAYERS**

- **NO COMPULSORY LAYER**

You can join **one of the disjunct layers INDEPENDENT**

- **DOWNLOAD LIMITATION OF CLIENTS**

Are not taken into account

## SCHEDULING

Chunk and peer scheduling is among the main driver of performance in P2P streaming systems.

- **SEQUENCE OF PACKETS AHEAD**

Need to be sourced as to **keep the streaming ongoing**

- **DIFFERENT STRATEGIES**

- **RAREST FIRST**

Good for P2P static distributing

- **URGENT FIRST**

Will congest the network

- **GEOMETRICAL DISTRIBUTION BASED**

Associate a **probability** to each chunk

- **SIZE OF SCHEDULING WINDOWS**

Different **strategies: 30s to 60s**

## INCENTIVE MECHANISM

Chunk and peer scheduling is among the main driver of performance in P2P streaming systems.

- **QUALITY PROPORTIONAL TO CONTRIBUTION**

- **DIFFERENT INCENTIVES**

Monetary based or **reciprocity-based.**

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## 7 VOIP

### VOIP

Voice over Internet Protocol is a methodology and group of technologies for the delivery of **voice communications over Internet Protocol**

- **ENCRYPTION**

- **MULTICAST**

- **FLAT PRICING**

- **INTEGRATION**

- **MULTIDEVICE**

## GENERATIONS

### • GENERATION 1

Server **handles** the connection between callers.

### • GENERATION 2

Server **proxies** the connections between callers, which **connects**.

### • GENERATION 3

Server only **provide login and indexing. ALMOST P2P**

## RTP - RTPC

The **Real-time Transport Protocol** is a network protocol for delivering audio and video over IP networks. **RTPC** controls the transmission (**desc, codecs, gateways**)

## SIP

Communications protocol for **signaling and controlling multimedia communication sessions** in applications of voice apps.

### • SETUP, CONTROL AND TERMINATE

Calls, allowing the **end-to-end** signalling.

### • TEXT BASED

### • URL FOR ADDRESS

### • SIMPLE

MESSAGE	DESC
REGISTER	Register and notify <b>the proxy</b> about url and IP
INVITE	Establish a media session between users
ACK	Confirm the connection is reliable
CANCEL	Terminates a pending request
BYE	Tears down the session
OPTIONS	Info about connection capabilities
SUBSCRIBE	Get notifications

## SKYPE

Skype is a telecommunications application software product that specialises in providing video chat and voice calls between devices via the **Internet and to regular telephones**.

### 1. PROPETARY SIGNALING

### 2. ENCRYPTION

AES256 keys **symmetric + RSA for exchange**

### 3. NAT AND FIREWALLS

### 4. WORK IN ALL NET CONDITIONS!

## ELEMENTS

### 1. CLIENTS

### 2. SUPERNODES

A node that can accept incoming TCP connections and do **signalling**.

Cache of super node with **200 elements always online**

### 3. LOGIN SERVERS

Authentication ensures names are **unique**

### 4. HTTP SERVERS

Used to fetch **updates**

## FIREWALL AVOIDANCE

### A. FIREWALL BLOCKS UDP

SNs List can not **refresh**. Try with a **TCP to some SNs**

### B. FIREWALL BLOCKS LOGIN SERVER

Authentication can not **login**. Try with a **SN as a relay**

## CALLING

- **DIRECT SIGNALING**

Carried with **TCP**

- **FIREWALL BLOCKS UDP**

Signaling with a **SN**

- **UDP STREAM**

Small overheads for media

## HOLE PUNCHING

*Hole punching is a technique in computer networking for establishing a direct connection between **two parties** in which one or both are **behind firewalls or NAT***

## CALLS FIREWALL AVOIDANCE

### ASYMMETRIC NAT

#### A. HOLE PUNCHING UDP

As to connect A to B

#### B. 4SNs AS RELAY

With a TCP stream between client and SNs

### SYMMETRIC NAT

#### A. HOLE PUNCHING NOT WORKING

#### B. 4SNs AS RELAY

With a TCP stream between client and SNs

## P2P SIP

*Peer-to-peer SIP is an implementation of a distributed **VOIP** or instant messaging communications application using a **P2P with DHT***

## 8 P2P Security

### WHY

- WHY WHO WHERE?
- NO CENTRAL AUTHORITY
- DATA INTEGRITY

### CLASSIFICATION

- BY TARGET  
Network, overlay or application layer
- BY EFFECTS  
Interruption, interception, modification, fabrication
- GOALS  
Passive or active
- IMPACT  
Disruptive or degrading

### APP-LAYER

1. LEGAL ISSUES
2. DATA BACKUP SERVICES
3. SYBIL ATTACKS
4. NODEIDS
5. SECURE ROUTING

### SYBIL ATTACK

*The Sybil attack in computer security is an attack wherein a reputation system is subverted by **forging identities** in peer-to-peer networks.*

- INFO ABOUT NODES, DATA, USERS
- dDOS
- $\text{HASH}(\text{IP}) = \text{NODE\_ID}$   
Need to have a **lot of IPs** as to do this attack.

### NODE IDS

*The NODE ID attack tries to **obtain a specific node ID***

- INFO ABOUT NODES, DATA, USERS
- dDOS
- RANSOMING NODE-ID
- ADD COMPUTATIONAL CHALLENGES  
As to compute the NodeID

### SECURE ROUTING

*Some malicious nodes may try to forward modified or invalid messages*

- SUPERNODES
- SYMMETRIC ENCRYPTION
- SECURE NODE-IDS

### TOR

*Tor is free software for enabling anonymous communication.*

### ONION LAYERS

- ENTRY RELAYS  
Provide access to the network
- RANDOM PATH
- KEY EXCHANGE  
Symmetric over a **temporary RSA**
- LAYERS PER RELAY  
Every relay decrypts **just a small portion** of the envelop.



## 9 Bitcoin

### BITCOIN

Bitcoin is a worldwide **cryptocurrency and digital payment system** called the first decentralised digital currency, as the system works without a central repository or single administrator.

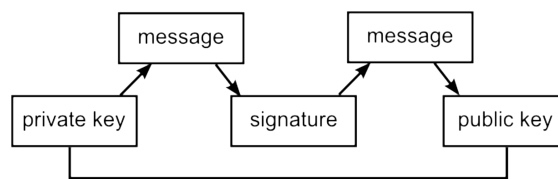
- P2P BASED
- VALUE ON SCARCITY
- BLOCKCHAIN

Links **between block** in the P2P network.

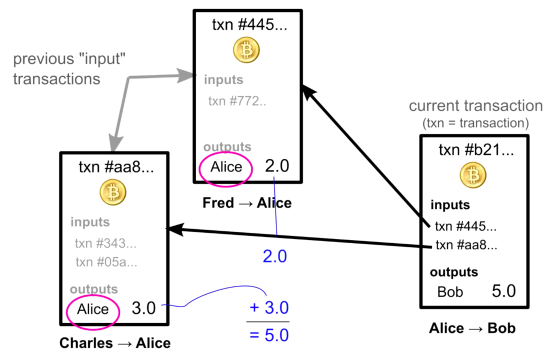
- TRUST = MATH
- FEE

Optional. **Miner** prioritise higher fees

- PUZZLE  
amount of **needed leading 0's** in output bit-string
- PUB/PRIVATE KEY SYSTEM



- TRANSACTION LIST - NO WALLETS



- NO-TIMESTAMP - DOUBLE TRANSACTION

Differences in propagation time. As soon as the **block is solved** is placed before another one which is **unsolved**.

**Mathematical race protects the network**

## 10 IoT Introduction

### DEFINITION

IoT is the network of **physical devices** embedded with electronics, software, sensors, actuators, and network connectivity which **enable these objects to connect and exchange data with the external environment.**

**THING to THING**

1. VERTICAL INTERFACES
2. EMBEDDED COMMUNICATION TECH
3. AUTOMATED DECISION MAKING
4. HUMAN UNATTENDED

#### A. RFID ROOTS

The RFID **ancestor** helped bringing to life IoT.

#### B. WSN NETWORK

Network of sensors **communicate** and gives data to an **automated decision making intelligence**

### LAYERS

#### • LAYER 0: HARDWARE

10+ Years **battery**  
1-2USD and **small scale and reliability.**

#### • LAYER 1: PHYSICAL

How can we assure that the **LAYER0 requirements** are met?

#### • LAYER 2: DATA LINK

Small bursts of **data**  
**Periodic**  
Huge **number of devices**

#### • LAYER 3: NETWORK

**Addressing, propagation of overhead** and coexistence with human traffic.

#### • LAYER 4: TRANSPORT

**Delay vs reliability.**

#### • LAYER 5: SESSION

No **security privacy and trust.**

#### • LAYER 6: PRESENTATION

Data visualisation for automated **decision and translation into formal language**

#### • LAYER 7: APPLICATION

**BM+Monetisation** and interactions with humans.

### CONCEPTS

1. M2M or MTC
2. EDGE or FOG COMPUTING
3. INDUSTRIAL or INDUSTRY 4.0
4. TACTILE INTERNET or INTERNET OF SKILL
5. BIGDATA
6. LIGHTWEIGHT CRYPTOGRAPHY

## 11 Wide-area IoT

### RAT

A Radio Access Technology or (RAT) is the underlying physical connection method for a radio **based communication network**.  
Bluetooth, Wi-Fi, and 3G, 4G or LTE.

1. MASSIVE AMOUNT OF DEVICES
2. ENERGY CONSUMPTION
3. COMMUNICATION RANGE
4. SIMPLICITY OF SOLUTION

#### 1. APPROACH1: WIFI

1. SCALABILITY
2. LOW-COVERAGE
3. DEVICES LIMIT
4. OVERHEADS

#### 2. APPROACH2: LTE

1. SCALABILITY
2. ENERGY REQUIREMENTS
3. SIGNALLING FOR CELLS

#### 3. SIGFOX - LoRaWAN - IEE 802.11ah - NB-IoT

### DOWNSIZING

#### • 2.4Ghz TO 900Mhz

Penetrability, power consumption, higher range

#### • 5MHz LTE to 180kHz to NB-IoT

Higher TX power **increases the range**

NAME	RATES	DpC	HW PRICE	RANGE
SIGFOX	UP: <b>100bps</b> DOWN: <b>600bps</b>	Millions	€2-5	>30 km
LoRaWAN	<b>300-50K bps</b>	Millions	€2-5	>30 km
WiFi Ha-Low	<b>150K-7800K bps</b>	8192	€4-8	>1 km
NB-IoT	UP: <b>20-250Kbps</b> DOWN: <b>35-240Kbps</b>	Millions	€2-5	>30 km

## 12 Local-area IoT Protocols

### STANDARDISATION

One of the biggest challenges in communication systems is **interoperability**

1. COMPATIBILITY
2. INTEROPERABILITY
3. COMMODISATION
4. SAFETY
5. QUALITY

	Bluetooth low energy	802.15.4	Wi-Fi	NFC	iRDA
Remote control	✓	✓	✓	✗	✓
Security	✓	✓	✓	✓	✗
Health and fitness	✓	✓	✓	✗	✗
Home and building	✓	✓	✓	✗	✗
Industrial	✓	✓	✓	✗	✗
Positioning	✓	✓	✓	✗	✗
Payment	✓	✗	✗	✓	✗
Automotive	✓	✗	✓	✓	✗
Comments	Largest ecosystem (phones, tablets, etc.). Low power.	Low power but closed ecosystem. Well-established in specific use cases e.g. smart energy.	Large ecosystem but high power consumption. Infrastructure connectivity is a bonus.	Low power but very short range.	Needs line of sight.

	Bluetooth low energy	802.15.4	Wi-Fi
Cost	✓	✓ (✓)	✓
Security	✓	✓	✓
Power consumption	✓	✓	✗
Ecosystem	✓	✗	✓
Reliability	✓	✓	✓
Ease of use	✓	✓	✓
Range	✓	✓ (✓)	✓

## 13 5G and D2D

### DEFINITION

5G planning aims at **higher capacity than current 4G**, allowing a **higher density** of mobile broadband users, and supporting **D2D** communication

- THOUSAND OF USERS
- HIGH SPEEDS  
10-20 Gbps in the cell
- SPECTRAL EFFICIENCY
- LOW-LATENCY
- D2D
- IoT

### APPLICATIONS

- IOT
- SMART DEVICES
- SMART CITIES
- TACTILE INTERNET
- AR & VR
- UBIQUITOUS INTERNET
- HIGH USER MOBILITY

## REQUIREMENTS

### User Experience

1. USER EXPERIENCE
2. EXPERIENCED DATA RATES
3. LATENCY

### Devices requirements

1. MULTI BAND AND MODE
2. RESOURCE/SIGNALING EFFICIENCY
3. DEVICE POWER EFFICIENCY
4. OPERATOR CAPABILITIES ON DEVICE

### System performance

1. CONNECTION DENSITY
2. TRAFFIC ENSITY
3. SPECTRUM
4. COVERAGE
5. SECURITY
6. AVAILABILITY

### Deployment and operation

1. COST EFFICIENCY
2. ENERGY EFFICIENCY
3. OPERATIONS
4. UPGRADES
5. ULTRA-LOW-COST

## D2D APPS

*D2D communication in cellular networks is defined as direct communication between **two mobile users without traversing the Base Station (BS)** or core network.*

### • IN-BAND COMMUNICATION

Different from out-of-band Bluetooth

- WEARABLE
- PROXIMITY TECHNOLOGIES
- INFRASTRUCTURE
- EMERGENCY
- M2M
- ADVERTISEMENT

- HOW TO MARKET
- BATTERY
- BENEFITS - OP AND US