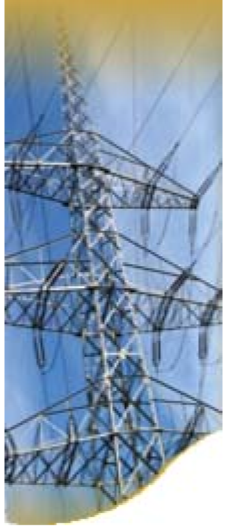


OFDM-Based High-Speed Narrowband PLC Approved for Smart Metering and Smart Grids

Agenda

- Motivation
- What is available for communications?
- Narrow Band vs. Broad Band
- DLC-2000 Communications Infrastructure
- Meshed PLC Networks
- Layer Structures
- Chip Architecture
- Protocols
- Medium Access
- Dynamic Routing
- Single Frequency Networking
- Summary & Conclusions

Motivation, what is ment to be SMART?

Competing Technologies

- Let people / consumers work
  = manual meter reading
- GSM / GPRS
- Fibre To The Home
- Cable TV
- Interferences
- Regulated Frequencies

Investment & RoI

- If the consumer like to receive e.g. a monthly bill, he is to read on his own behalf
- Infrastructure is for free, strong dependency on cost, availability and connectivity
- Huge investment into new fibre grid, will only be possible in newly developed locations
- New communications provider comes on board, dependencies between utility, consumer and cable TV provider
- Dimmer and other phenomena could become eliminated, if the currently unregulated frequency band above 150 kHz becomes regulated

What Else to Power Line Communications?

- PLC competes with
  - Field-busses on dedicated wires like CAN, ProfiBus, ..
  - Voice-band- / DSL-modems on telephone lines
  - Local area networks (Ethernet, ...)
  - Radio based systems (ISM, Bluetooth, wireless LAN, DECT, ...)
  - Cellular networks (GSM, UMTS, ... ⇒ operation expensive)

- Power Line Communication is not Power Line Communication
  - Narrow vs. broad band
  - In house vs. LV & MV grid communications
  - Synchronization, Modulation, Channel coding, MAC concept, routing ⇔ flooding, supported communication services

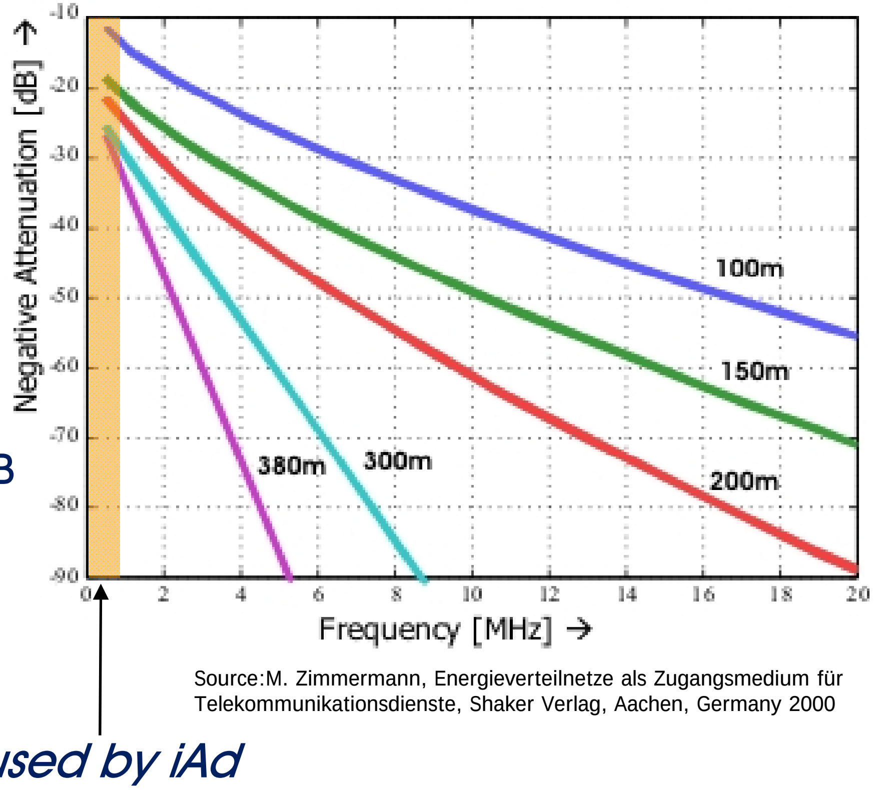
Characterisation of Power Line Communication Systems

	Low Data Rate Narrow Band	High Data Rate Narrow Band	Broad Band
Frequency Range	9 – 148.5 kHz	9 – 500 kHz A-Band 9-95 kHz B-Band 95-125 kHz BCD-Band 95-148.5 kHz other Bands	1.5 – 50 MHz
Data Rate	< 10 kbps	50 kbps < … < 1 Mbps	> 10 Mbps
Technology	FSK frequency shift keying BPSK binary phase shift keying FFH fast frequency hopping SFSK dual ch./ spread DCSK dif. chirp shift keying	OFDM orthogonal frequency division multiplex, MCM multi carrier modulation differential coding	MCM / COFDM, Bit loading
Forward Error Correction (FEC)	no or low	strong (for high reliability designed)	medium (for maximum throughput designed)
Applications	Automatic Meter Reading, European Installation Bus, Power Line Area Network	Airfield Lighting AGLAS, Energy Management, Smart Grids & Metering AMR/AMM Automated Meter Reading / Management	Last mile Telecom, Internet, Voice over Internet Protocol (VoIP), High definition television (HDTV)
Companies, Organisations	Busch Jaeger, Echelon, Görlitz, Ytran, Renesas AMI Solution, Landis&Gyr	ADD Grup, iAd, Maxim, Prime (ADD, Current Group, Landis+Gyr, STMicroelectronics, Usyscom, ZIV, …)	Amperion, Current, DS2, Homeplug, Mitsubishi, OPERA, Panasonic, Spidcom

Narrow Band vs. Broad Band

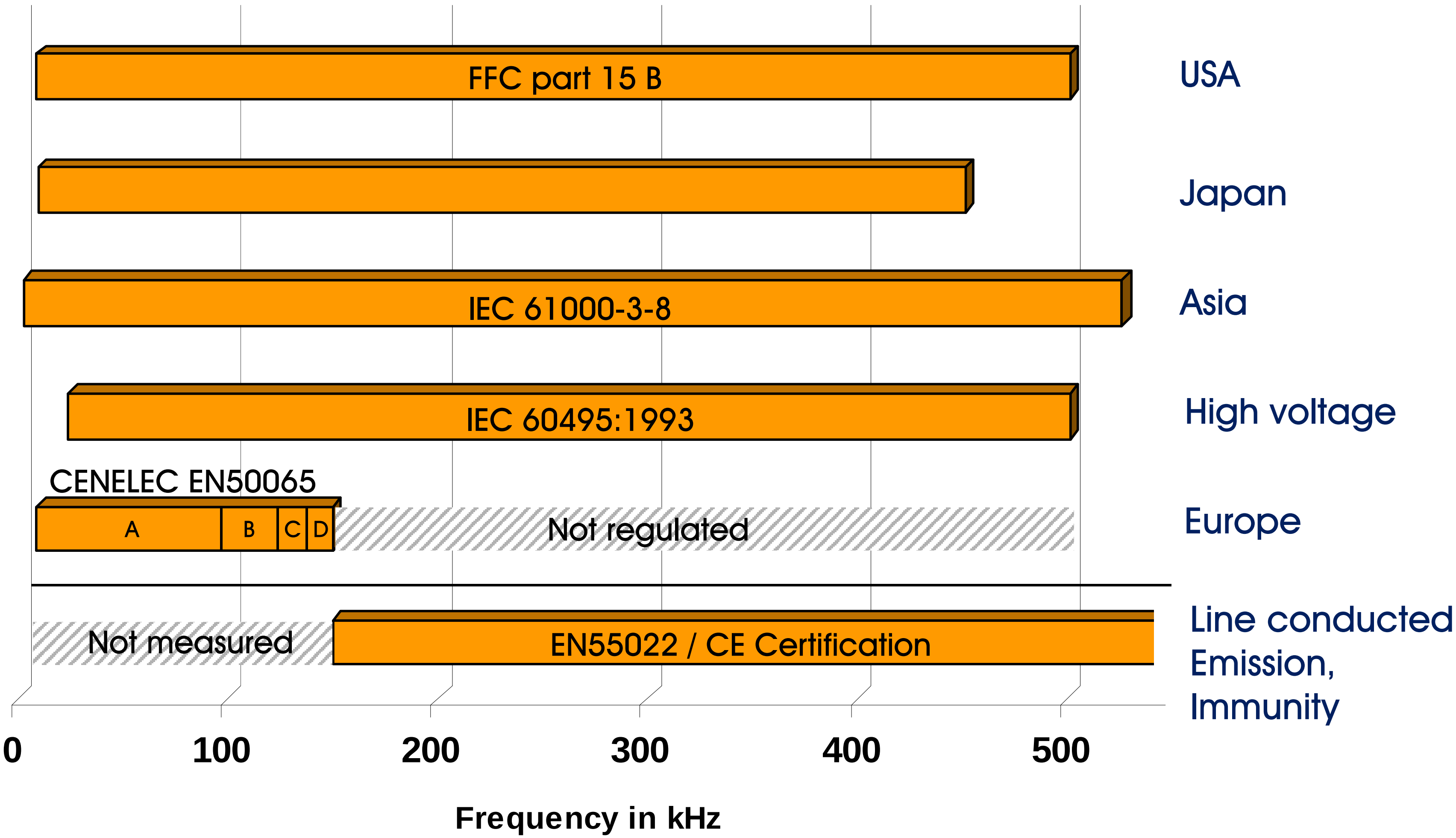
- Requirement
  Coverage of large areas on existing infrastructure (MV- and LV-grid)
- Frequency range < 500 kHz
  – Much lower attenuation
    longer distances
  – Reduced number of repeaters
    lower costs
    more redundancy
  – Narrowband
    data rate between
    100 kbps ... 1Mbps
  – Regulation: CENELEC / FCC 15 part B
  – No interference with SW radio
- Independent and parallel use with BPLC (1.5-30MHz) on one Power-Line

Length profile of the attenuation models for different cable lengths in LV access network



Source:M. Zimmermann, Energieverteilnetze als Zugangsmedium für Telekommunikationsdienste, Shaker Verlag, Aachen, Germany 2000

Frequency Regulation / EMC

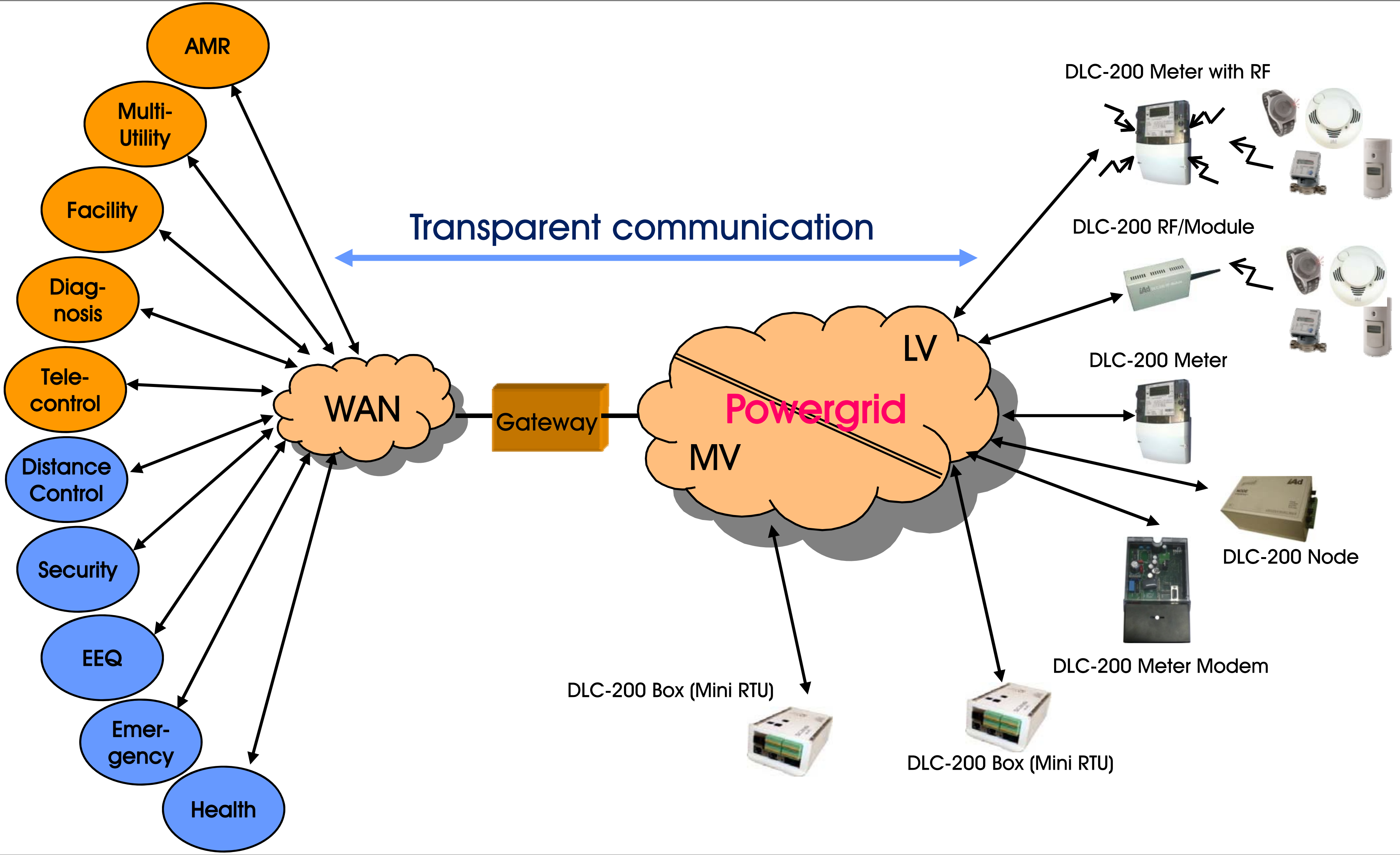


- Coexistence of CENELEC communication and existing equipment not ensured
- One communication standard, which uses several frequency bands

Requirements on Smart Grid PLC system

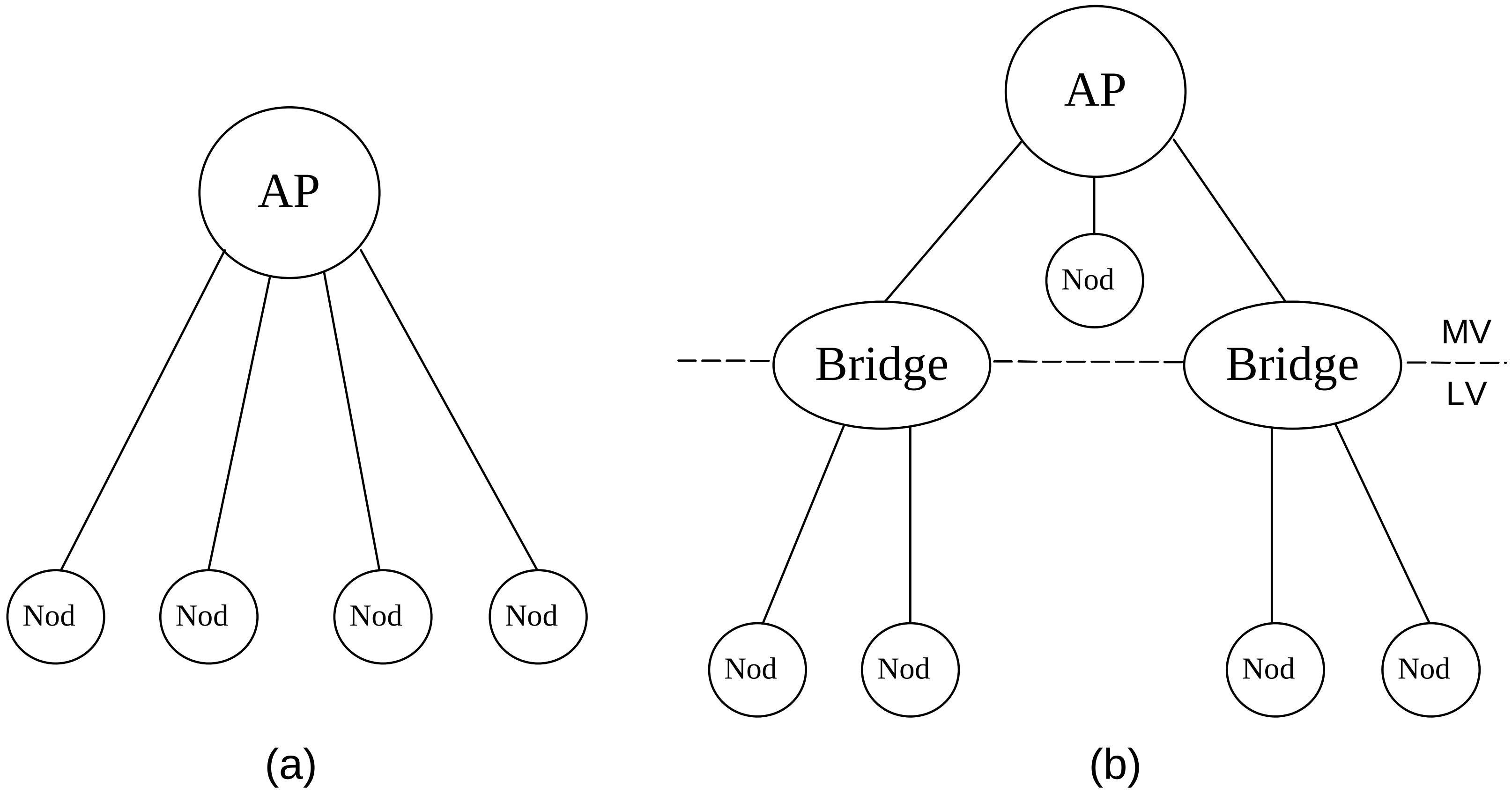
- High speed narrowband PLC
  - Data rates > 50 kBit/s
- One communication standard, which uses several frequency bands
  - Cenelec A 9-95 kHz
  - Cenelec B 95-125 kHz
  - Cenelec BD / BCD 95-148,5 kHz
  - FCC Bands 150 – 500 kHz
- PLC system as communication infrastructure
  - Supports several applications
  - Different protocols
  - No data warehouse or data concentrator
- PLC System for MV and LV or LV only

DLC-2000 is Communication Infrastructure

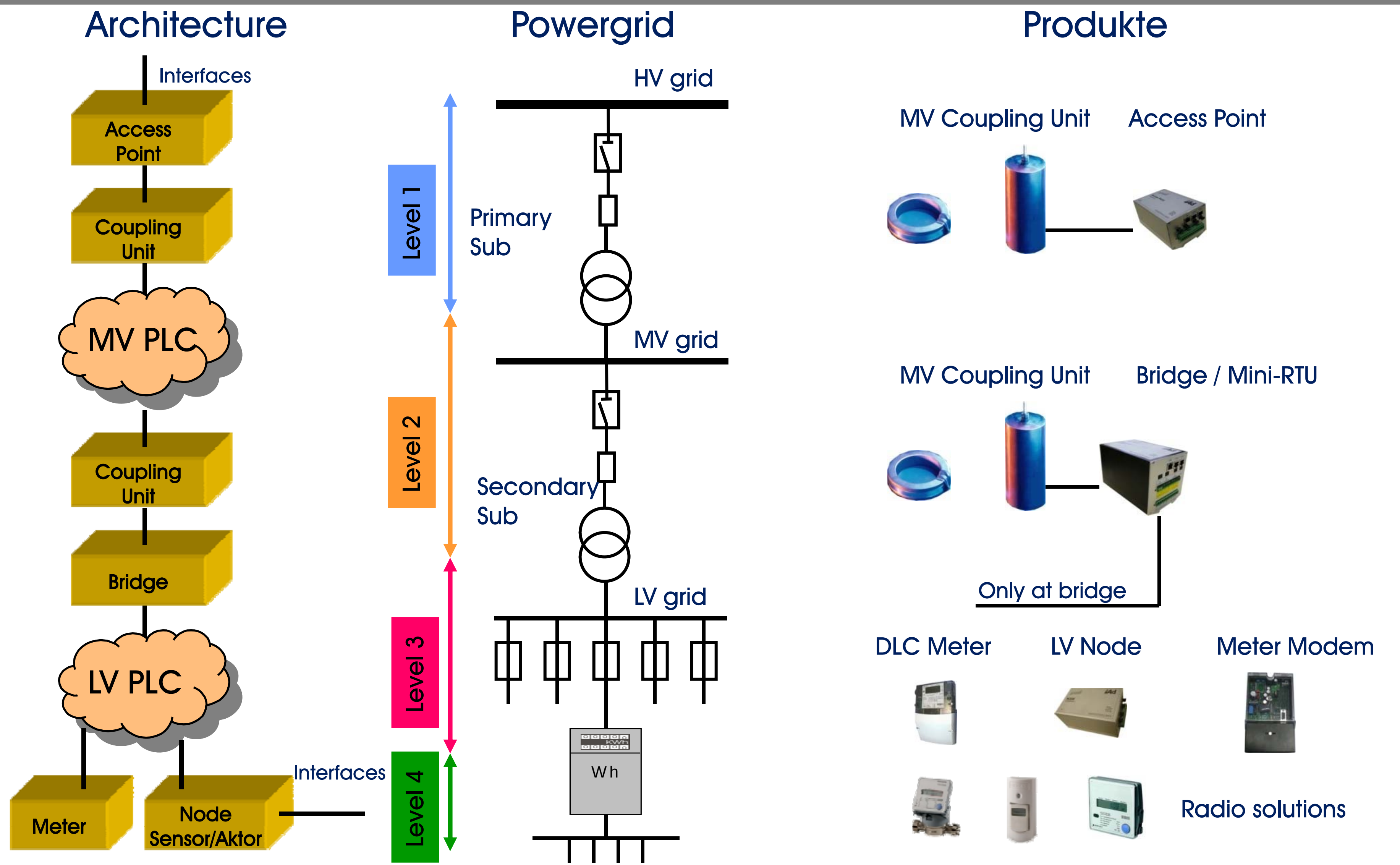


DLC-2000 System for MV and LV or LV only

- **Simple PLC network layout with one (a) or two (b) cascades**

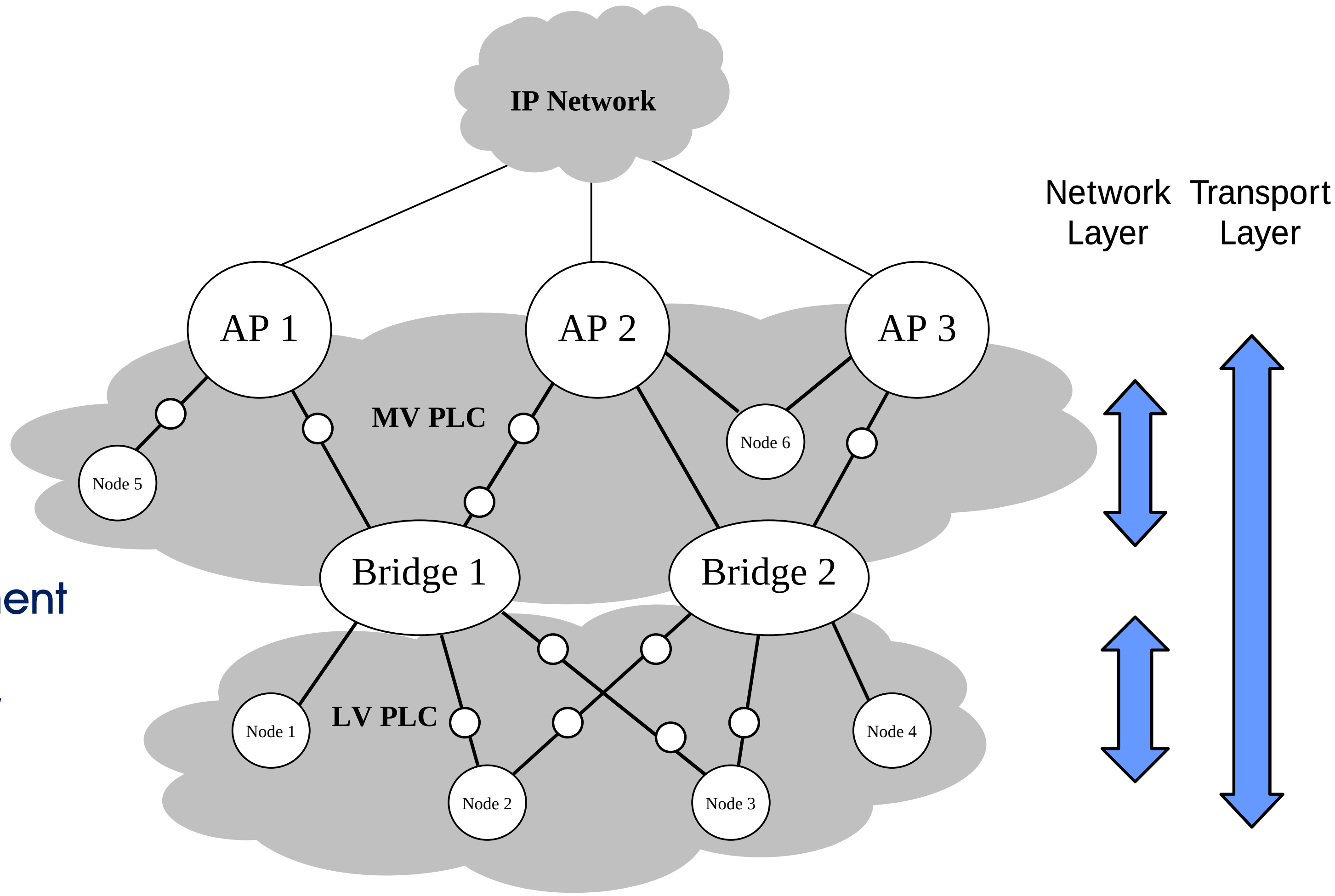


DLC-Components in the System

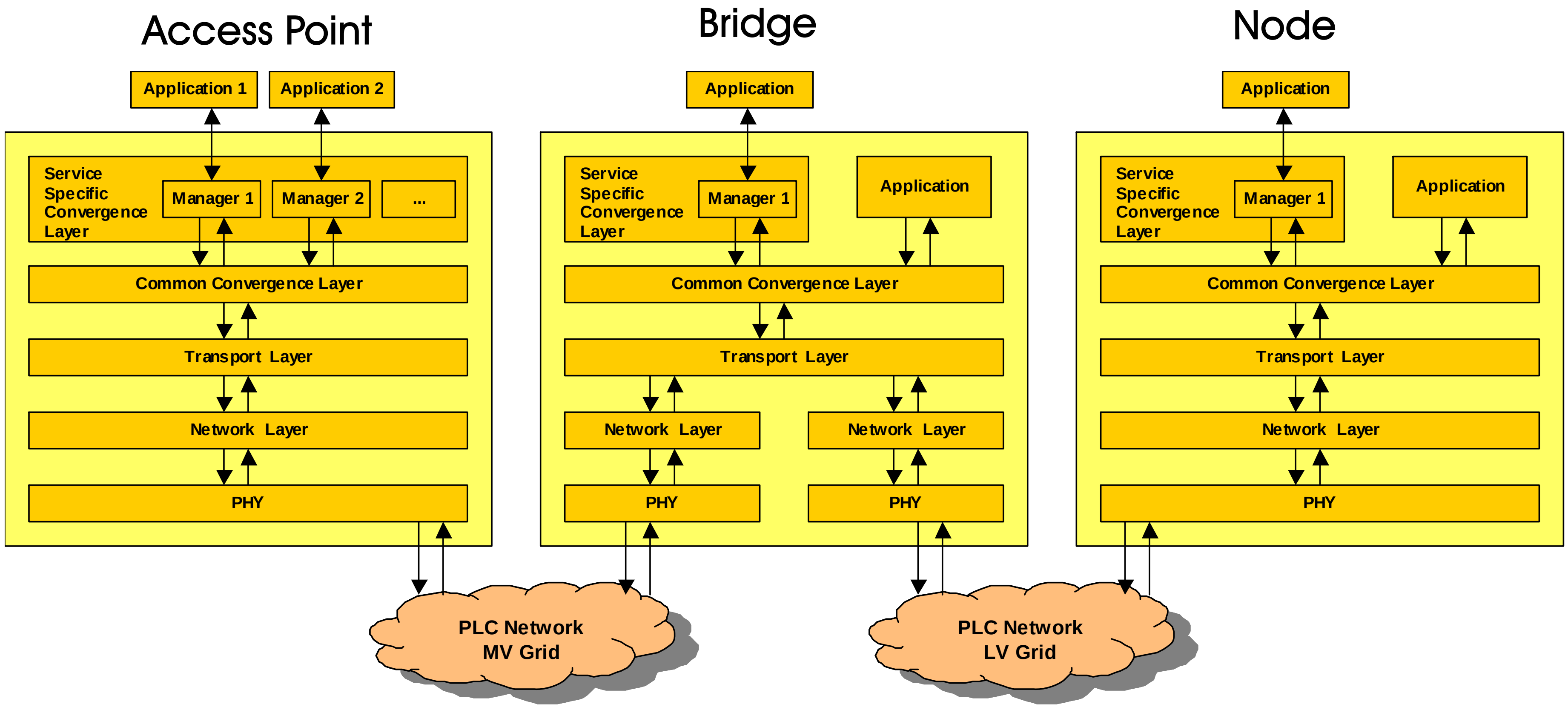


Meshed PLC network

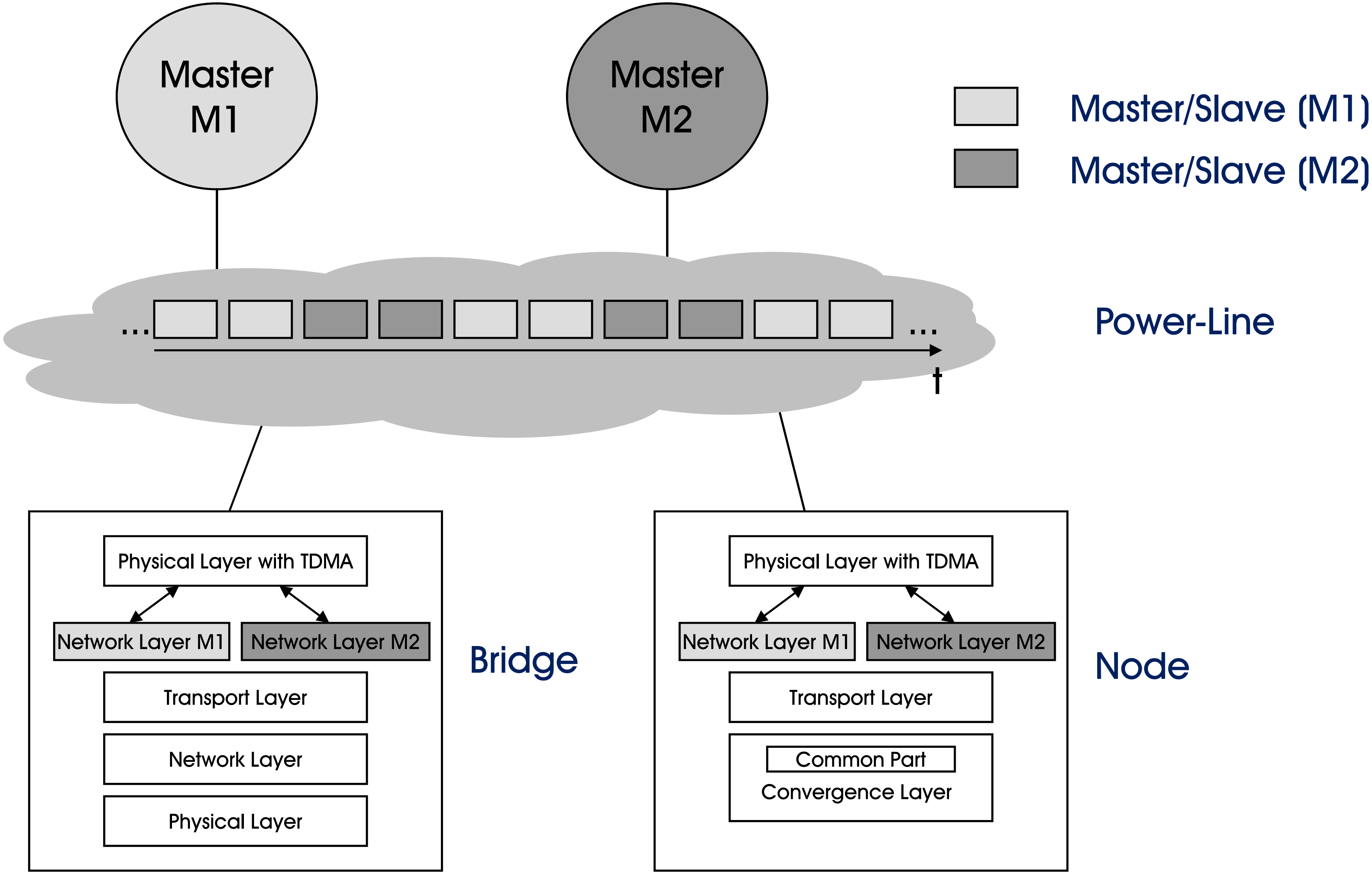
- Bridge Routing
- Access Point Routing
- Redundancy handling
- QoS Management
- Segmentation / reassembly



Layer Concept DLC-2000



Layer Structure for multi-master system



Requirements on Lower Communication Layers

- Low „electro smog“
- Coverage of long distances / large areas on existing infrastructure
- Large number of participants
- Control and security applications ⇒ **real-time requirements**

⟹ **completely independent communication blocks**

- High attenuation of the channel (cabel 1 dB/km, branch 2-8 dB)
- No direct link to every client ⇒ **No bus**

⟹ **Repeater are necessary**

- Transmission quality changes over time
- Topology of network is often unknown

⟹ **Automatic routing**

  – Meshed MV-networks with variable switch configuration
  – Guaranteed reaction time and other real-time requirements

➔ **Ad hoc networking with very fast reaction times is required for ‘SmartGrids’ applications**

Physical Layer

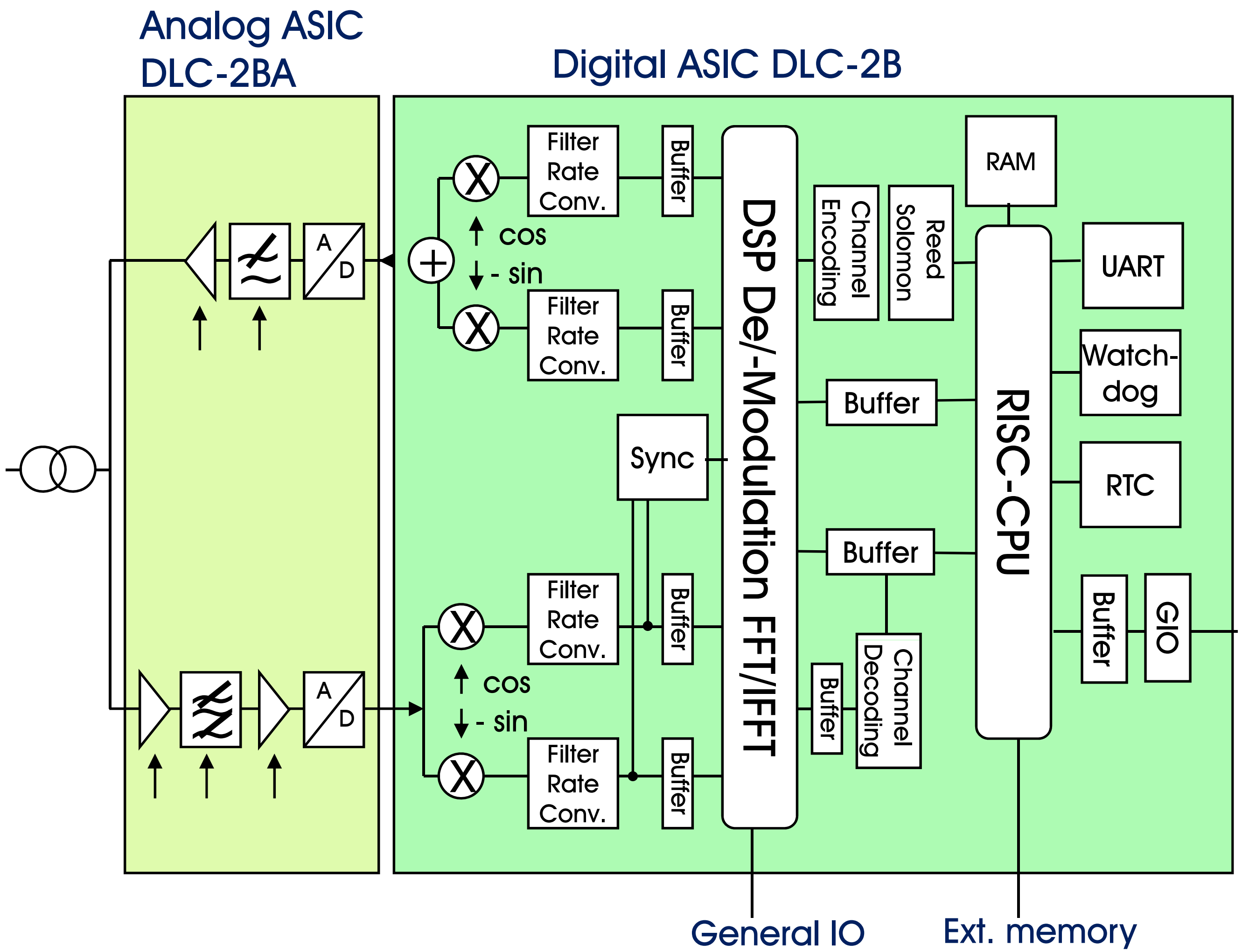
- Transmit blocks of date from one device to an other device
  - Block synchronisation
  - Channel equalisation
  - Modulation / Demodulation
  - Forward Error Correction
- Time Synchronisation
  - Accuracy > 1ms over overall network
- FDMA as service for network planning
- TDMA to support
  - Multi master communication (➔ roaming)
  - Hybrid medium access technologies

Approach for Independent Transmission Blocks

- full dynamic range for every block
- dynamic gain adaptation (impedance-variance)
- Energy normalized correlation
- OFDM (multi-path propagation / interference)
- differential coding along the frequency axis (no channel estimation, no carrier phase synchronisation, no time-variance)
- special demodulation against in-band narrow-band noise, coloured noise, impulse noise
- Convolutional coding and soft input Viterbi decoding

→ no information about the channel necessary

Architecture of DLC-2B System on Chip



DLC Chip

- High-Speed Narrow Band Power-Line Chipset for integrated solutions
  - Data rate up to 500 kBit/s
  - Band-width and carrier frequency freely configurable
  - Complies with CENELEC and FCC
- Low-Cost Chipset DLC-2B/BA with 8-Bit RISC Processor
- High Performance Chipset DLC-2C/CA in combination with hyNet

Analysis of Application Protocols

- For the different applications a lot of protocols are already defined e.g. DLMS, IEC 870-5-10x, M-Bus, Konnex, ...
  - Mainly packet oriented protocols with short package length (20-128 Bytes)
  - Point to Multi-Point communication
  - Automation:
    Hierarchical organized Applications $\Rightarrow$ Master - Slave structures
  - Facility Management
    Client - Server relationships (sensors provide information)
    Poll and push operations
- Almost all traffic flows between one single point and all other communication points

➔ **Throughput at one single point defines system performance**

Medium Access Techniques

- Two classes:
  - controlled medium access
    - protocol or structure avoids any collision
    - e.g. master-slave bus protocols, token ring, and TDMA
  - concurring or random medium access techniques
    - collisions can happen
    - e.g. Aloha, Slotted Aloha, CSMA, CSMA/CD or CSMA/CA
    - due to hidden nodes in PLC no carrier sensing possible

    ⇒ for small packets only Slotted Aloha usable

    - maximum throughput of Slotted Aloha is 36.8%
    - e.g. IEEE 802.11b sees a throughput of 2-4 Mbps (11 Mbps), if several stations are talking

+ Hybrid medium access like Homeplug AV (CSMA/CA + TDMA)

Favorite Medium Access

- Traffic and channel characterization:
  - concentration of dataflow on single point
  - small packets
  - lot of participants
  - relatively high WERs are possible
- Central organization of channel access on this point

  ➔ **Master / Slave System**

  - free of collision
  - allows master a 100 % throughput
  - for downlink optimum solution
  - if master knows about communication request of slave (to master or other slave), very efficient solution possible.
  - Polling of slaves with ensured minimum channel usage (e.g. 10-20%) for spontaneous data form slave

Automatic and Dynamic Routing

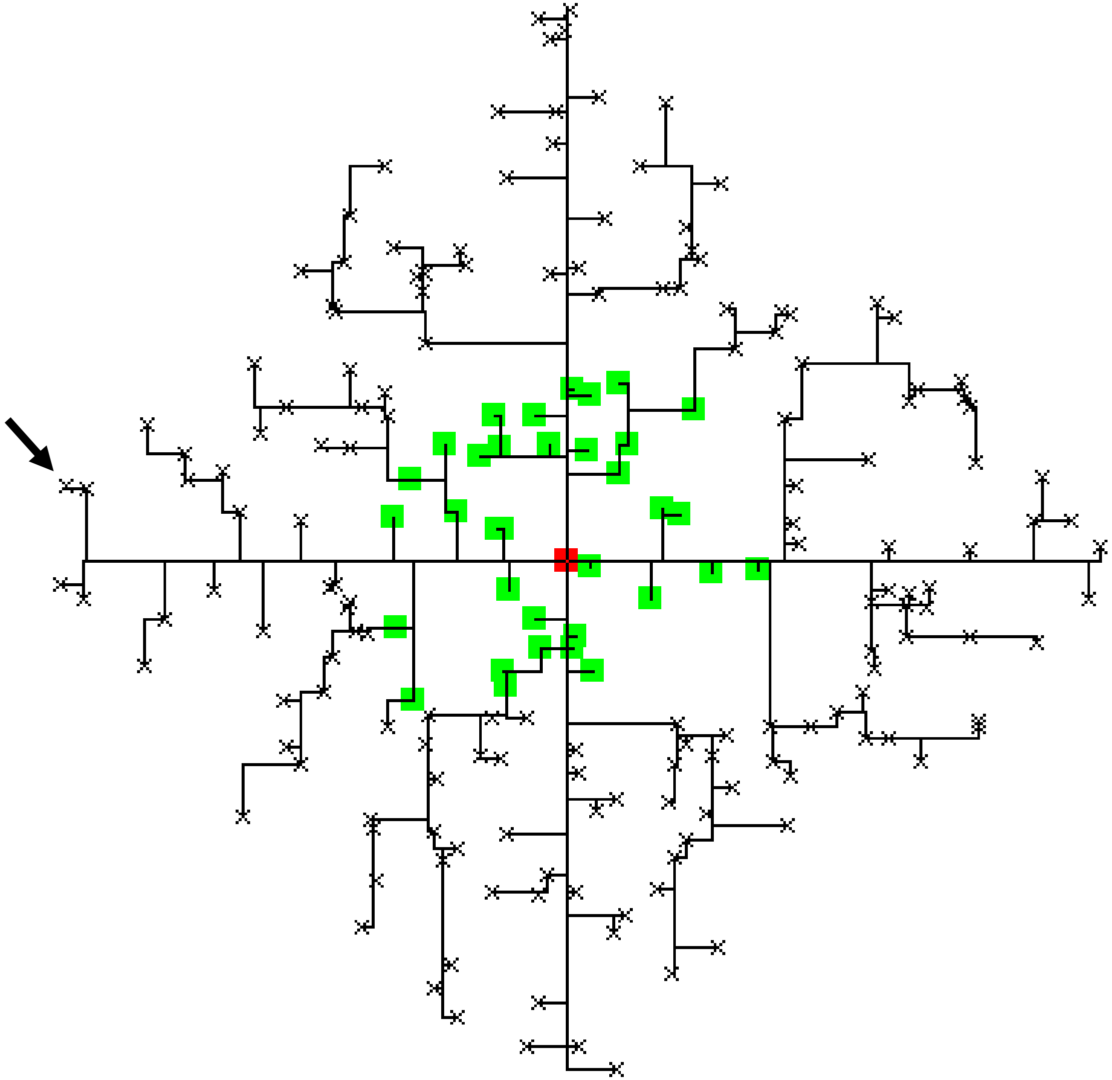
- Channel: No direct link to every client
- Every participant is a possible repeater for other devices
- Classical routing in central organized networks
  - Slaves inform master about possible repeaters
    - ➔ in dynamic networks a permanent update is required
  - Master calculates routing table
    - ➔ Repeater addressing in every packet
  - Complete reorganization after dramatic topology changes
  - exponential increase of effort for every repeater level
- A Single Frequency Network based flooding concept

  e.g.: All participants who have correctly received a packet retransmit this packet at the
  same time, on the
  same medium and the
  same frequency ➔ **SFN**

SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

1. Master transmit request

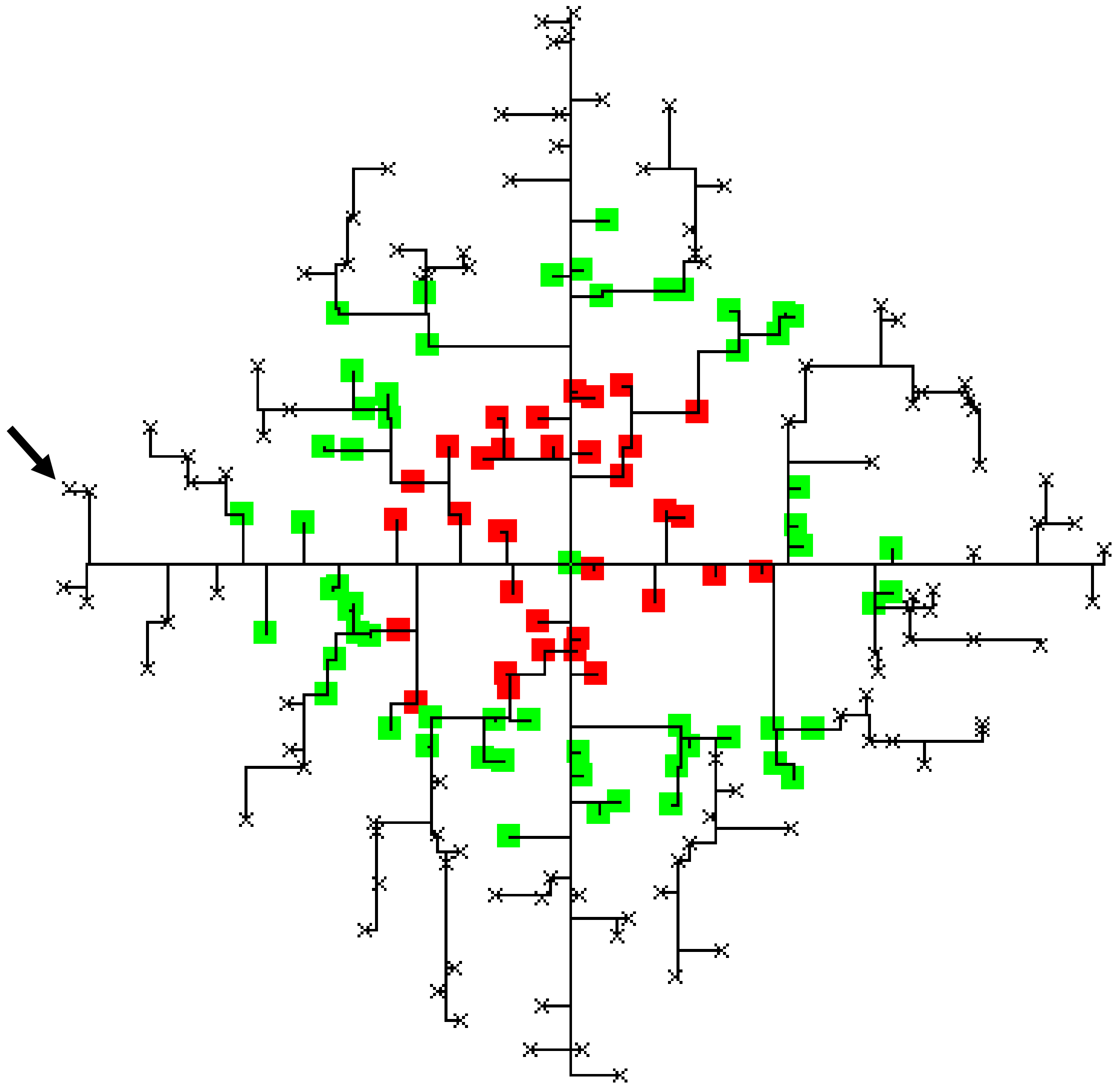


SFN-Flooding

- Channel model with 200 randomly distributed participant

- Request / Response service

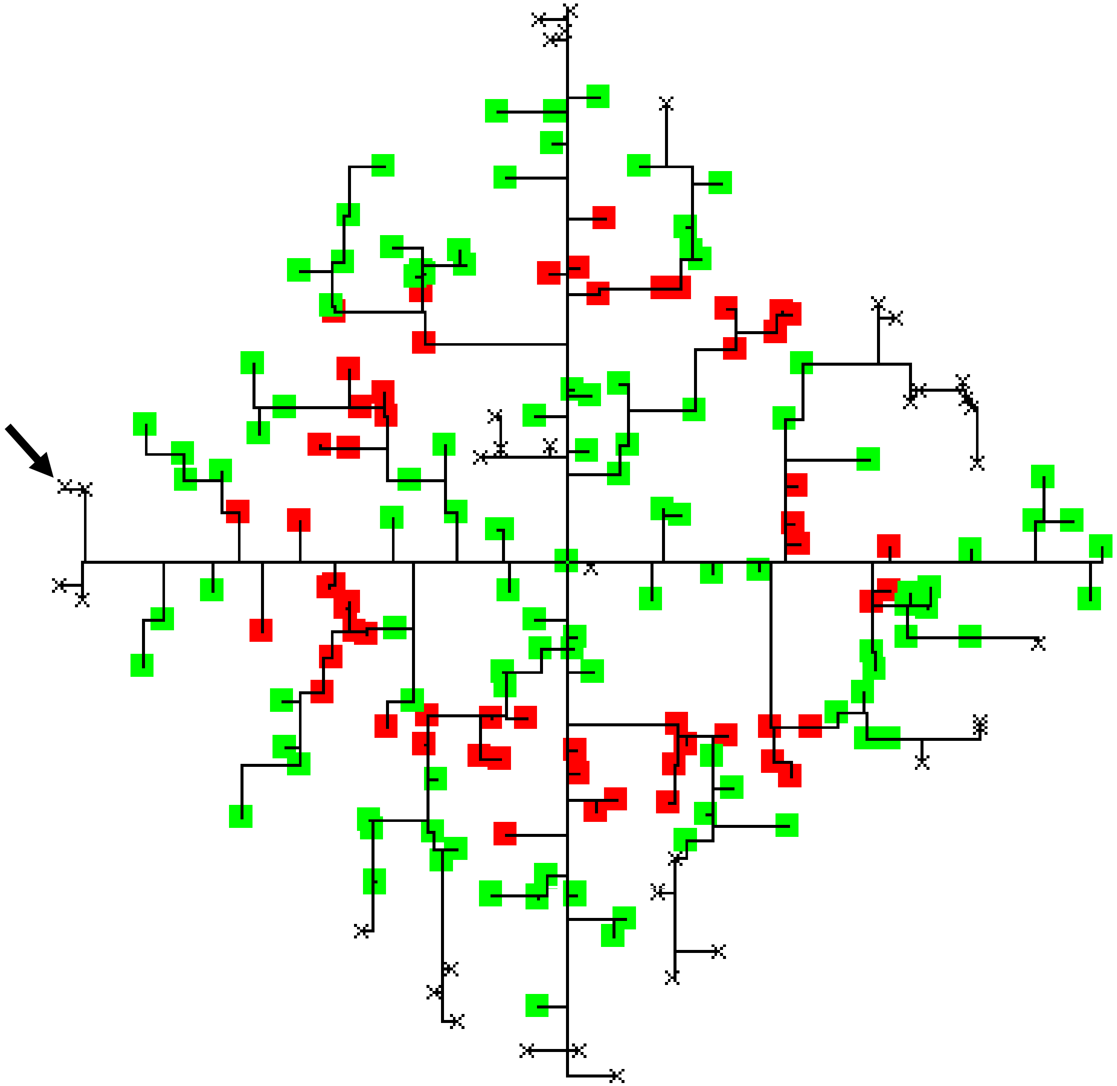
1. Master transmit request
2. First repetition



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

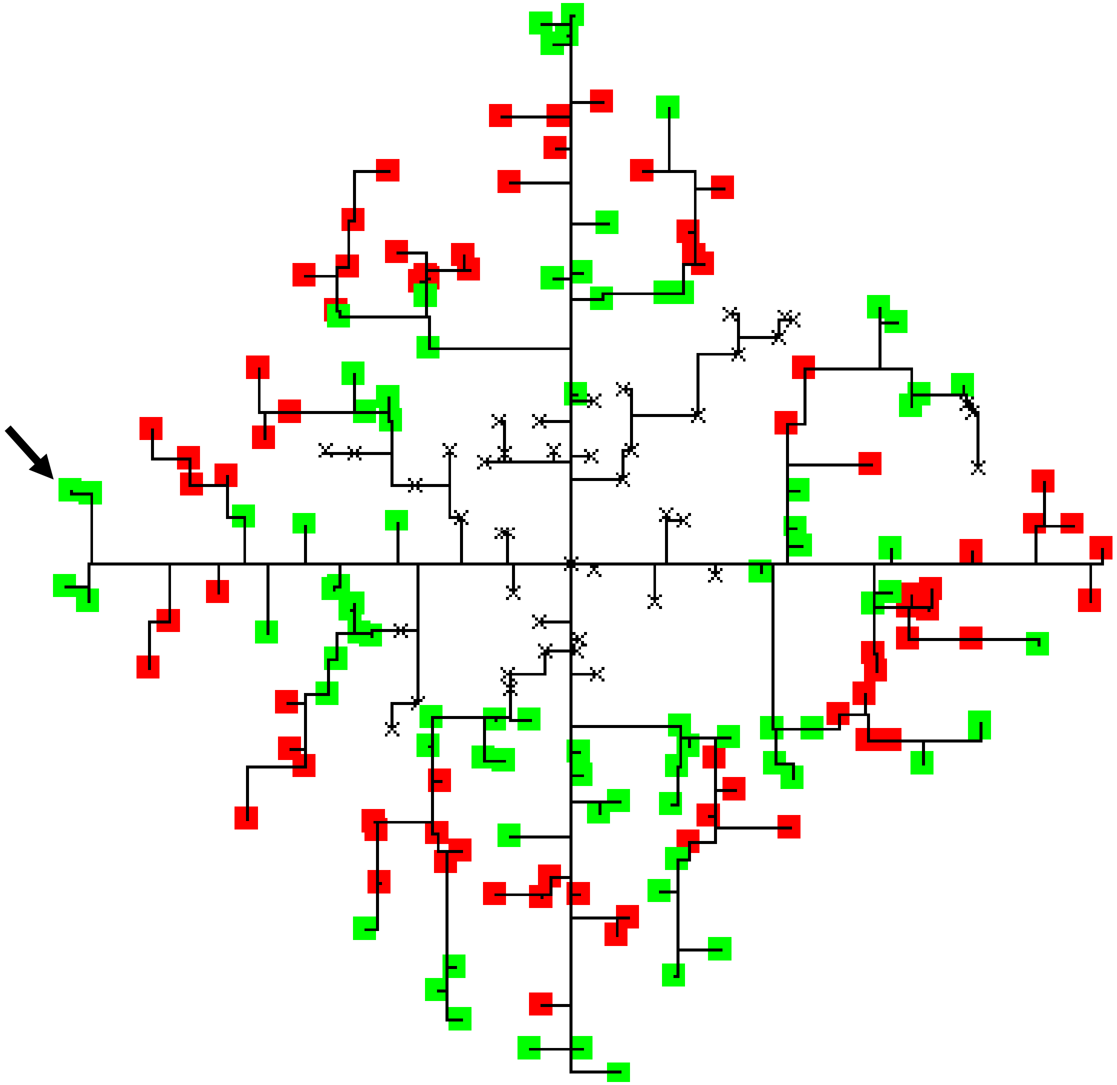
1. Master transmit request
2. First repetition
3. Second repetition



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

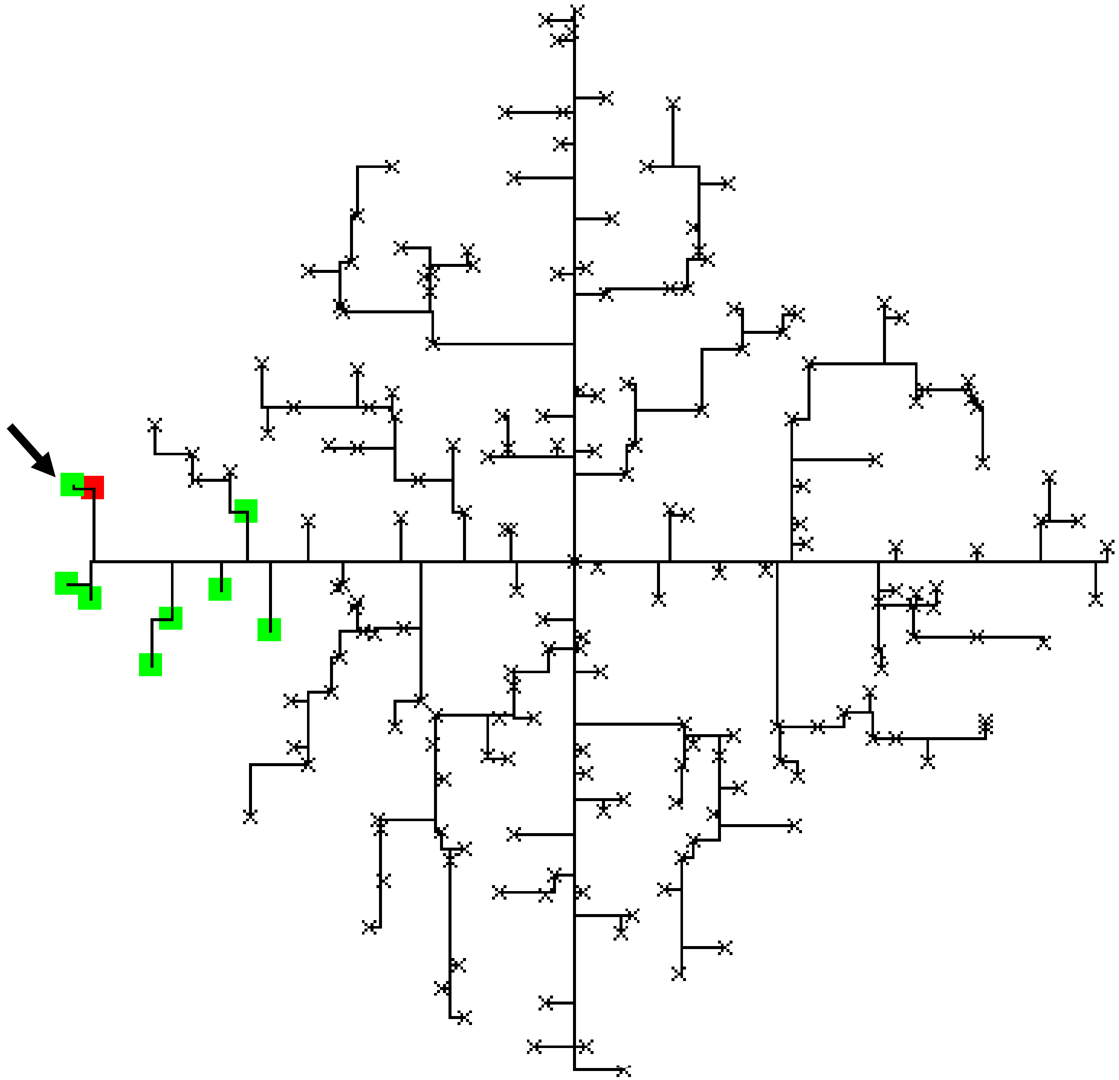
1. Master transmit request
2. First repetition
3. Second repetition
4. Third repetition



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

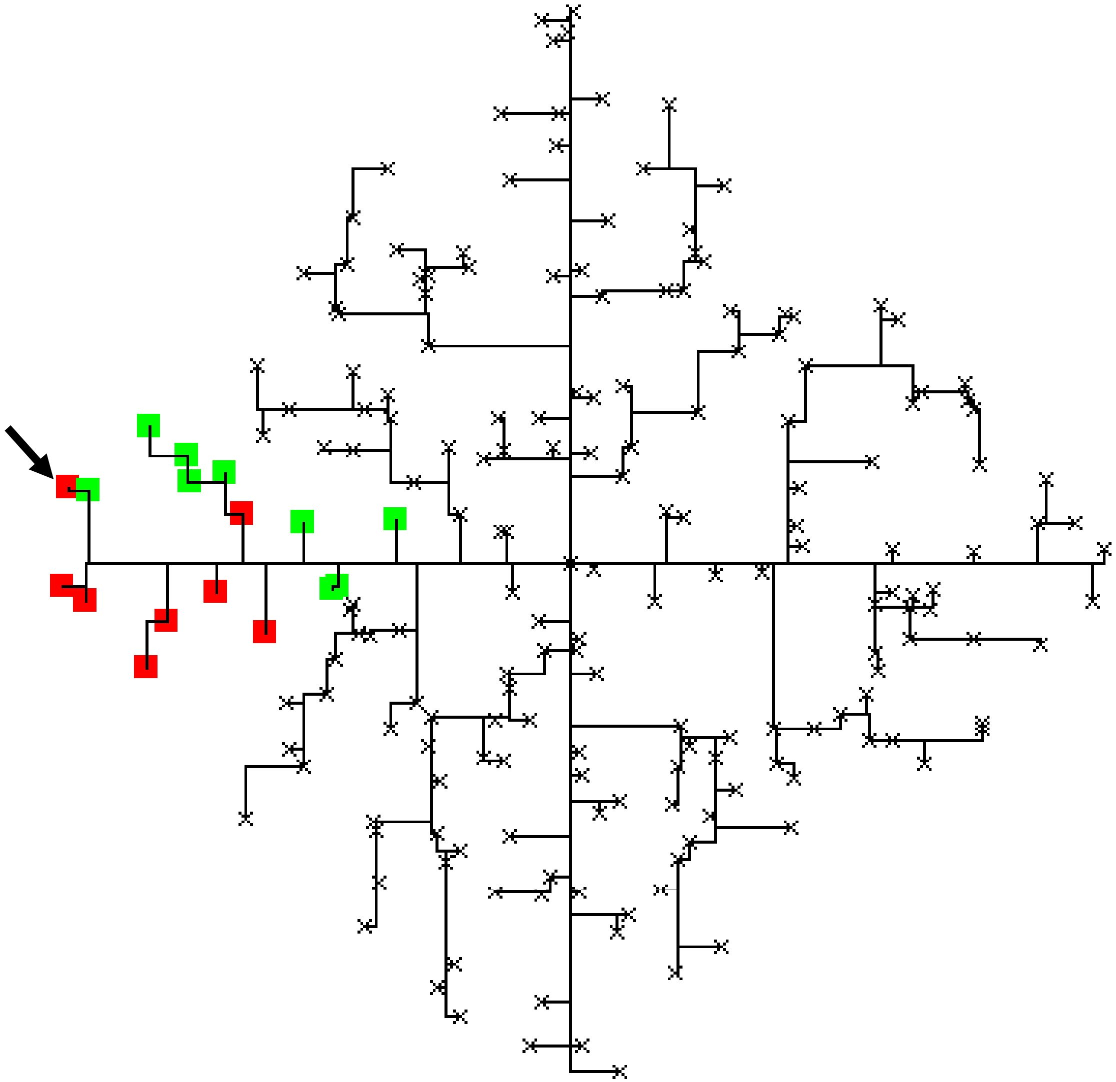
1. Master transmit request
2. First repetition
3. Second repetition
4. Third repetition
5. Slave transmit response



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

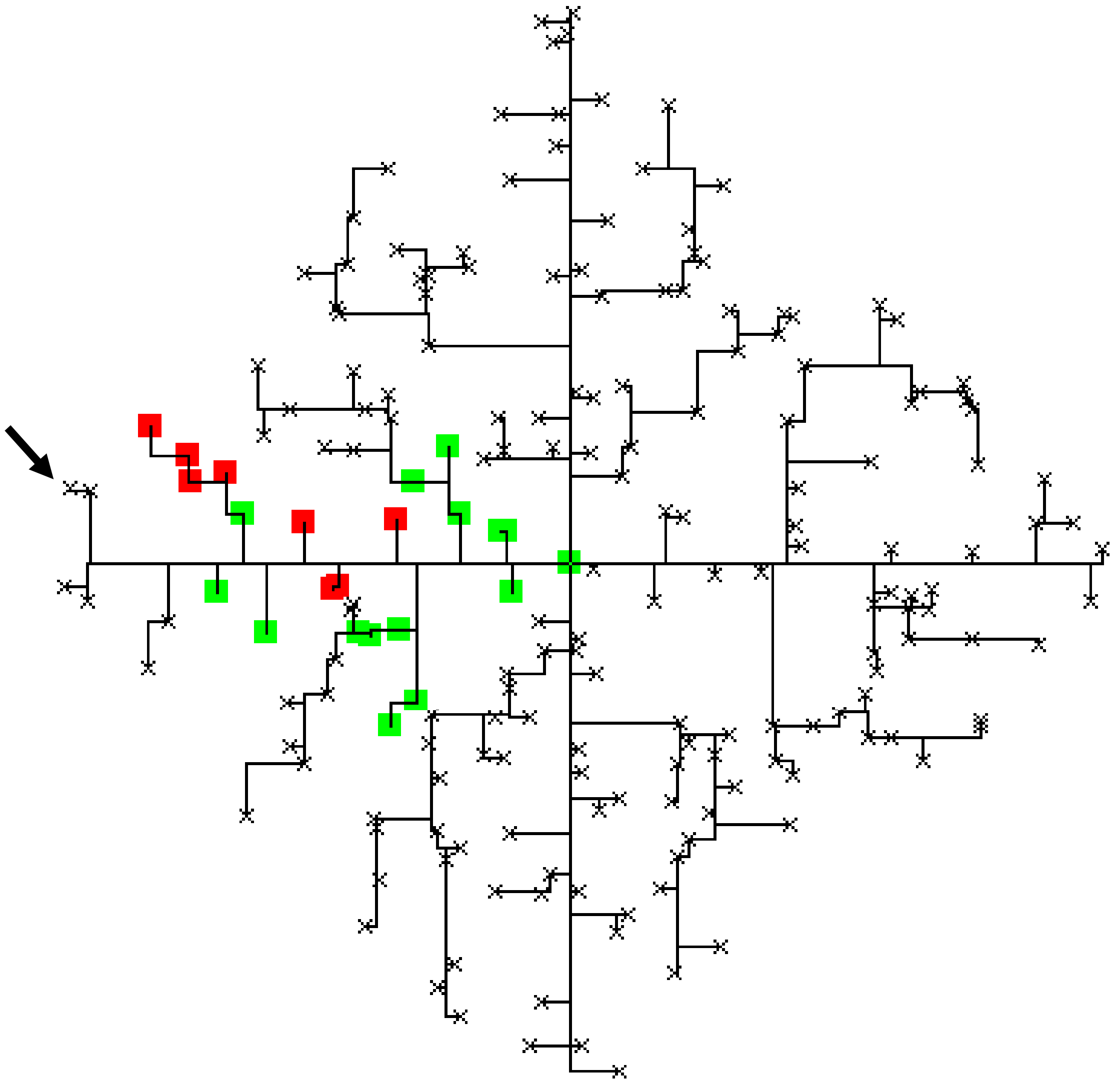
1. Master transmit request
2. First repetition
3. Second repetition
4. Third repetition
5. Slave transmit response
6. First repetition



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

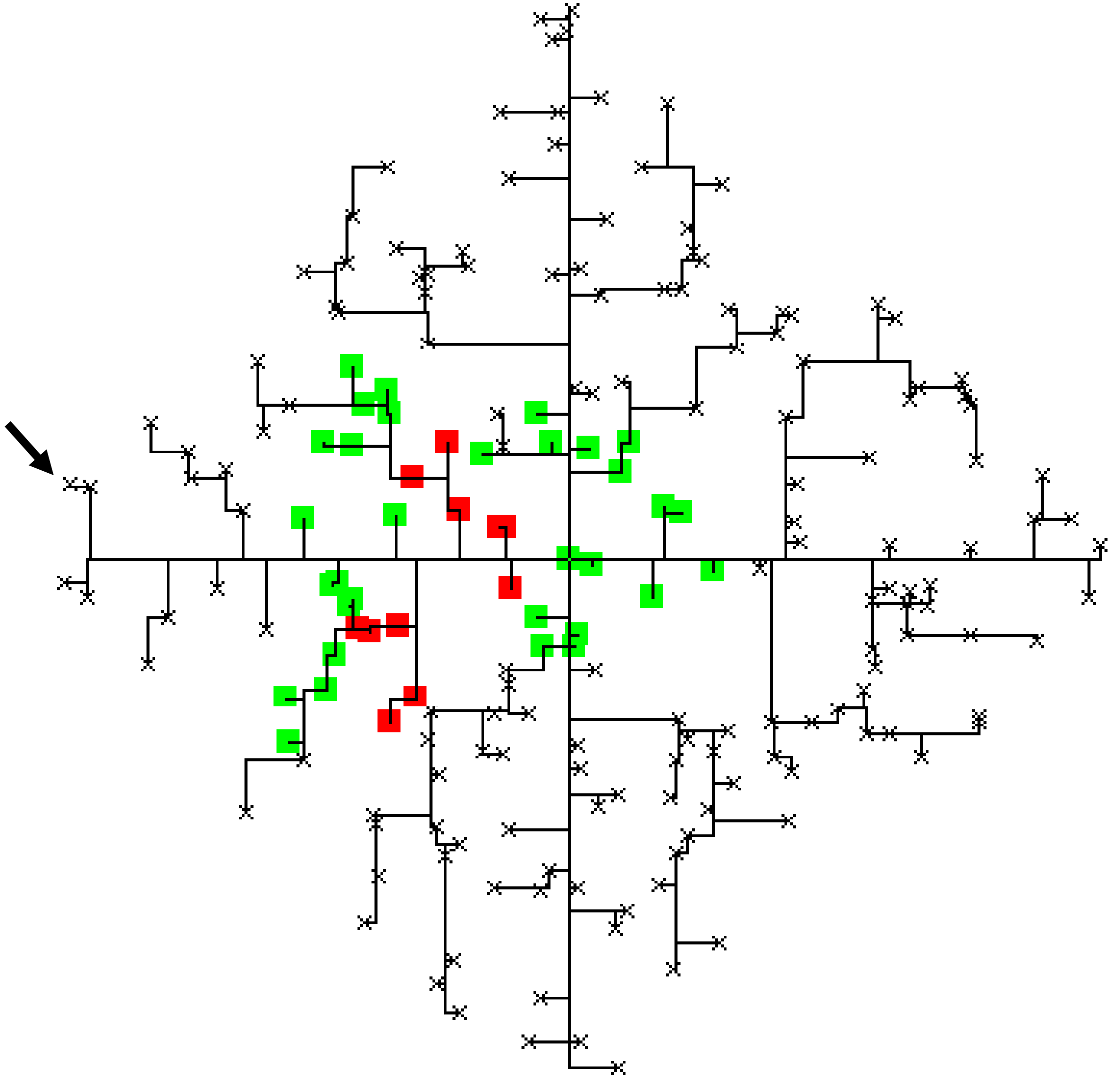
1. Master transmit request
2. First repetition
3. Second repetition
4. Third repetition
5. Slave transmit response
6. First repetition
7. Second repetition



SFN-Flooding

- Channel model with 200 randomly distributed participant
- Request / Response service

1. Master transmit request
2. First repetition
3. Second repetition
4. Third repetition
5. Slave transmit response
6. First repetition
7. Second repetition
8. (Third repetition)



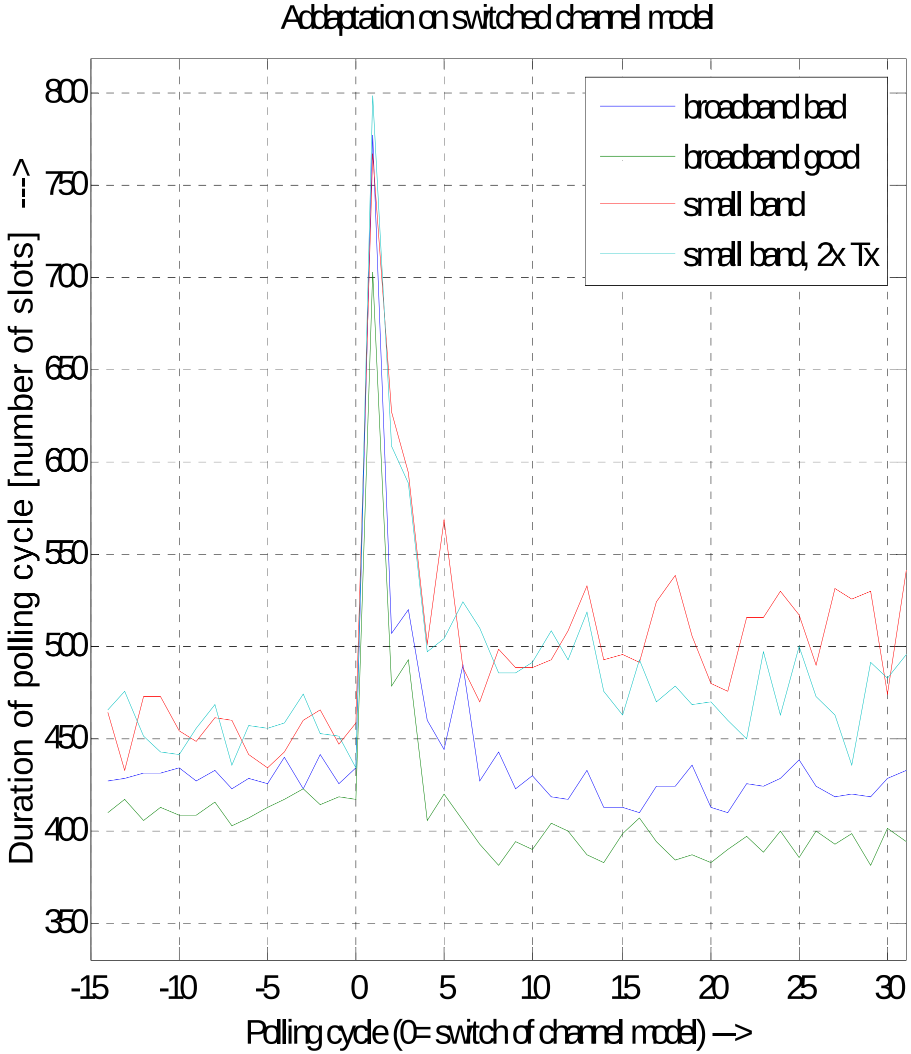
Comparison between Routing and Flooding based System

- For this analysis we assume:
  - Packet oriented physical layer with fixed packet size
  - Master – slave system
- The characteristic criteria are:
  - Average protocol overhead
  - Packet rate of packets transmitted only for routing and networking purposes
  - **Average duration of a polling cycle (single packet)**
  - Average duration of a broadcast
  - Average logon time without any channel information
  - *Reaction to slow changes of the network*
  - **Reaction to abrupt changes of the network**

Reaction to Abrupt Changes of Network

- At time 0 channel model changed from ring_100 to tree
- routing based system will logout, search and login most of the slaves (interruption for minutes)
- flooding based system reaches all slaves within first polling cycle
  - maximum 5 (7) retries
  - doubled duration
- second polling cycle 30% more efficient
- after 5 polling cycles channel adaptation finished (< 1 min.)

➔ Fast ad hoc networking



Strength of MAC concept

- Ad hoc networking with very fast reaction times is required for ‘SmartGrids’ applications
- Throughput at one single point defines system performance
- Master / Slave system for central organization
- Logical independent channels for pipelining, Multi-Master, ...
- Single Frequency Network based flooding concept for networking
- Comparison between routing and flooding based system
  - less overhead
  - easier management
  - much faster broadcast and login
  - higher throughput
  - very fast reorganization on channel or topology changes

Summary & Conclusion

- Market segment: High speed narrow band PLC
- Coexistence of CENELEC communication and existing equipment is not ensured
- One communication standard, which uses several frequency bands
- DLC – 2000 can be used either in CENELEC- or between 150-500 kHz
- DLC – 2000 is communication infrastructure
- System structure
- Layer concept
- Already known: Power Line is a time variant and difficult channel
- Specialized PHY with powerful channel coding is required
- Chipsets available
- Throughput at one single point defines system performance
- 'SmartGrids' applications require ad hoc networking and roaming
- SFN based flooding concept