Lemcko & INCASE project study day

Combining Power and Data

UGENT Campus Kortrijk, 20/02/2019

Power Line Communications: *From fundamentals to applications*

Prof. V. Moeyaert

Electromagnetism & Telecommunications Department

veronique.moeyaert@umons.ac.be

UMONS Université de Mons

POLYTECH MONS

Abstract and acknowledgments

"The PLC field of telecommunication engineering is progressing towards maturity. This presentation proposes a review of fundamentals technologies and standards that enable its implementation. A survey of present and future applications is also presented."

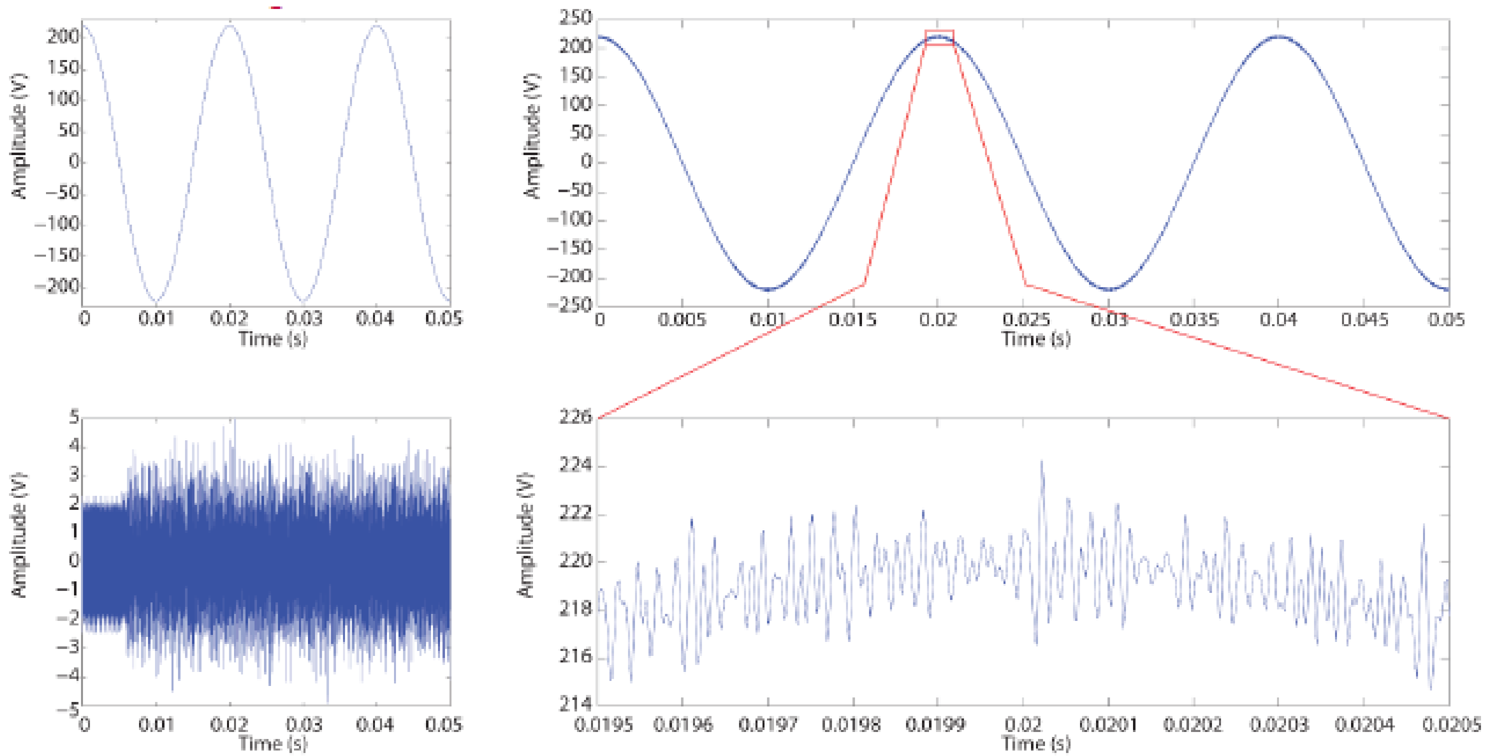
Thank you to some past and present colleagues for their contribution:

G. Bayot, S. Bette, T. Diakese, P. Mégret, A. Van Laere,

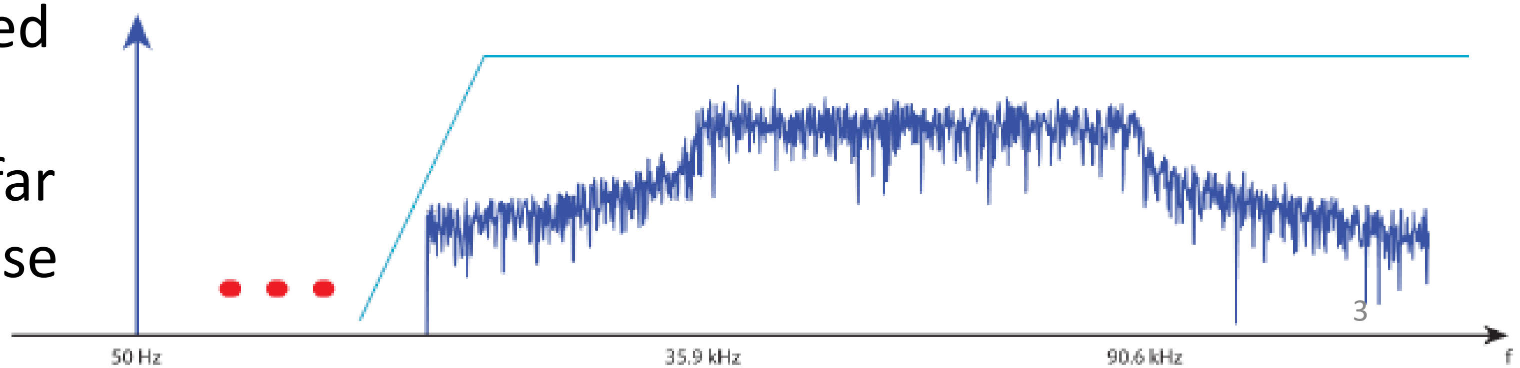
C. Wawrzyniak

PLC (Powerline Communications) concept = carrying data on the top of the main

Low energy signal superimposed to the power wave

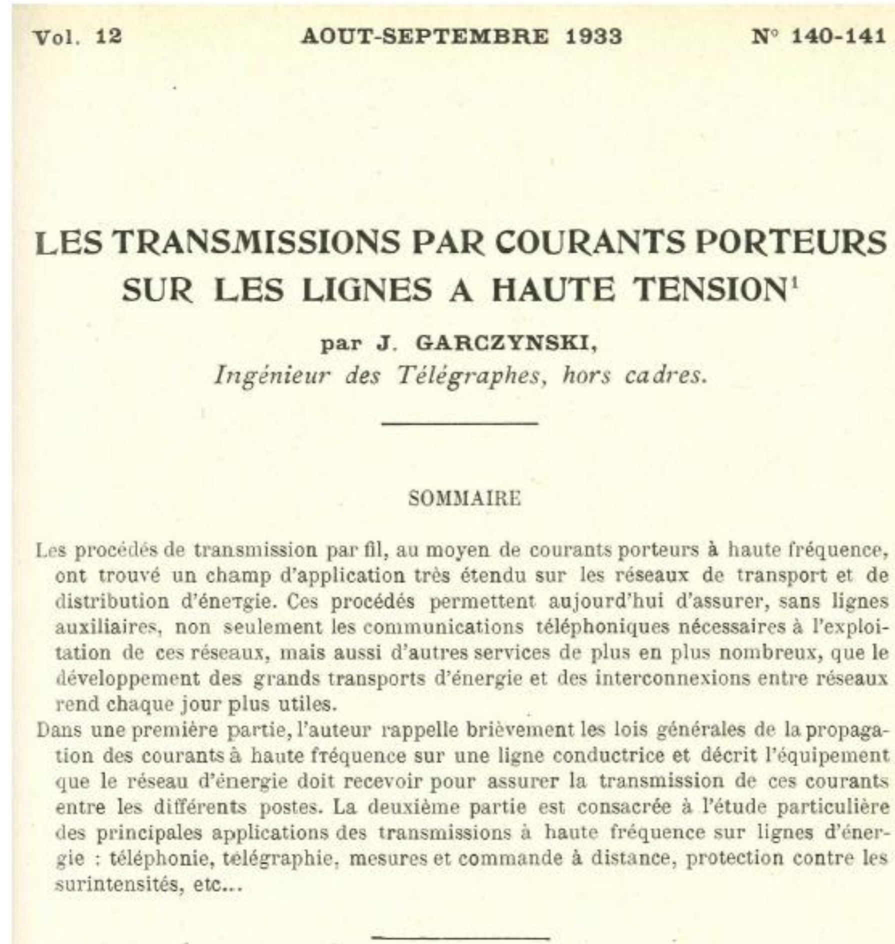


Frequency used for data transmission far from 50Hz (case of NB-PLC)



History of PLC – not a recent concept! *[9], [10]*

≈1920	Patenting of analogue voice communications on HV lines
1933	HF transmission (France) on HV grids for **telemetry** (L'onde Electrique)
From the 50s	'Ripple Carrier Signalling' on MV and LV grids on a carrier frequency between 100 Hz and 1 kHz for **street lights control** and **tariff switching**
From the 80s	Beginning of researchs about unidirectionnal transmissions on power lines on the 5-500 kHz frequency band
Early 90s	Beginning of domestic electrical lines fo broadband communications
Late 90s	Digital duplex low bit rate transmission
From 2000	Standardisation of both low and high bit rates transmission systems & All-round research



Vol. 12 AOUT-SEPTEMBRE 1933 N° 140-141

LES TRANSMISSIONS PAR COURANTS PORTEURS SUR LES LIGNES A HAUTE TENSION[1]

par J. GARCZYNSKI,
Ingénieur des Télégraphes, hors cadres.

SOMMAIRE

Les procédés de transmission par fil, au moyen de courants porteurs à haute fréquence, ont trouvé un champ d'application très étendu sur les réseaux de transport et de distribution d'énergie. Ces procédés permettent aujourd'hui d'assurer, sans lignes auxiliaires, non seulement les communications téléphoniques nécessaires à l'exploitation de ces réseaux, mais aussi d'autres services de plus en plus nombreux, que le développement des grands transports d'énergie et des interconnexions entre réseaux rend chaque jour plus utiles.

Dans une première partie, l'auteur rappelle brièvement les lois générales de la propagation des courants à haute fréquence sur une ligne conductrice et décrit l'équipement que le réseau d'énergie doit recevoir pour assurer la transmission de ces courants entre les différents postes. La deuxième partie est consacrée à l'étude particulière des principales applications des transmissions à haute fréquence sur lignes d'énergie : téléphonie, télégraphie, mesures et commande à distance, protection contre les surintensités, etc...

PLC transmissions ….

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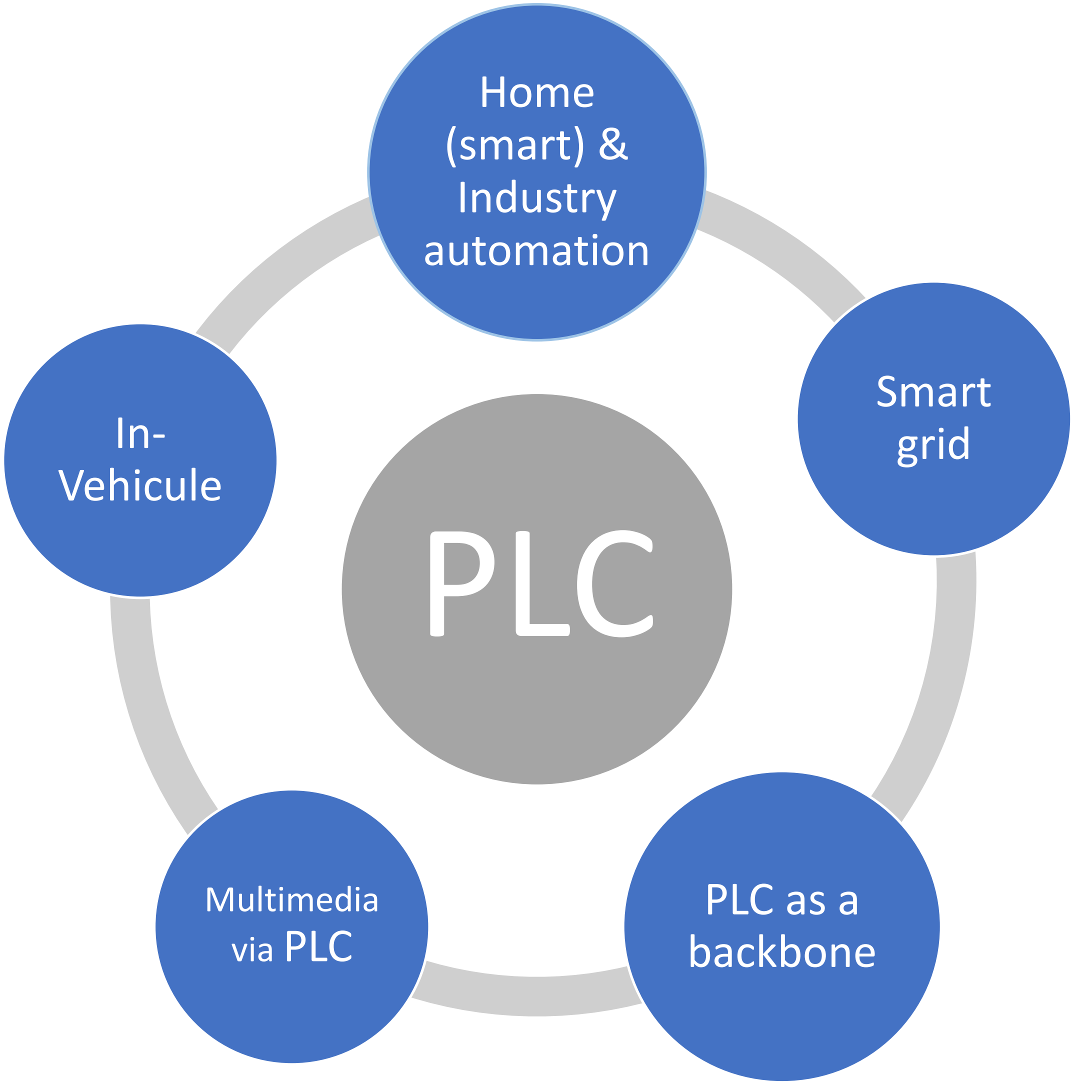
Cost effectiveness due to the dual use of power line	Rough transmission environment
Competitor of wireless transmissions	
Multiple applications in various scenarios	

PLC applications



Outline

- Standards governing PLC technology
- Channel & noise models & characteristics
- Modulation and processing for PHY PLC
- PLC MAC layer principles
- Application of PLC technology
- PLC modems manufacturing
- Future directions in research

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PLC classification according to frequency bands

UNB-PLC

NB-PLC

Name	Frequency	Wavelength	Applications
VLF	3 kHz–30 kHz	100 km–10 km	submarine com.
LF	30 kHz–300 kHz	10 km–1 km	marine com.
MF	300 kHz–3 MHz	1 km–100 m	AM broadcasting
HF	3 MHz–30 MHz	100 m–10 m	military, amateur radio
VHF	30 MHz–300 MHz	10 m–1 m	FM radio, TV
UHF	300 MHz–3 GHz	1 m–10 cm	TV, radar
SHF	3 GHz–30 GHz	10 cm–1 cm	satellites, radar
EHF	30 GHz–300 GHz	1 cm–1 mm	radar
Opt. Com.	10^3 GHz–10^7 GHz	0.3 mm–30 nm	Optical com.

BB-PLC

Belgian frequency plan: https://www.bipt.be/en/operators/radio/frequency-management/frequency-plan

PLC classification according to frequency bands & bit rates

- 3 classes of PLC technologies → different challenges
  → large ecosystem of standards
- UNB-PLC: Ultra-narrowband PLC
  - 125Hz to 3kHz (ULF)
  - 100 bit/s (2 bits per main cycle) over up 1 km
  - Historically for Ripple Carrier Signalling
  - UNB solutions are proprietary
- NB-PLC: Narrowband PLC
  - 3 to 500 kHz
  - LDR (Low Data Rate – a few kbps):
    - SDO (Standards Developing Organisation) based: KNX, Spread-FSK, …
    - Non-SDO based: Insteon, X10, …
  - HDR (High Data Rate – 10 to 500 kbit/s):
    - SDO based: ITU-T G.hnem, IEEE 1901
    - Non-SDO based (but standardized): PRIME, G3-PLC

PLC classification according to frequency bands & bit rates

- BB-PLC: Broadband PLC
  - 1.8 to 100 MHz (IEEE bound) or even 300 MHz (ITU bound)
  - From several Mbit/s to 1 Gbit/s
  - SDO based: HomePlug (1.0, av, av2), IEEE 1901, ITU-T G.hn
  - Non-SDO based: HomePlug Green PHY, MediaXtreme

- HDR-NB-PLC and BB-PLC of interest in this presentation

- Not to be forgotten:
  - Interoperability
  - Coexistence
  - EMC

PLC operating bands defined by CENELEC/FCC/ARIB (NB), IEEE and ITU (BB)

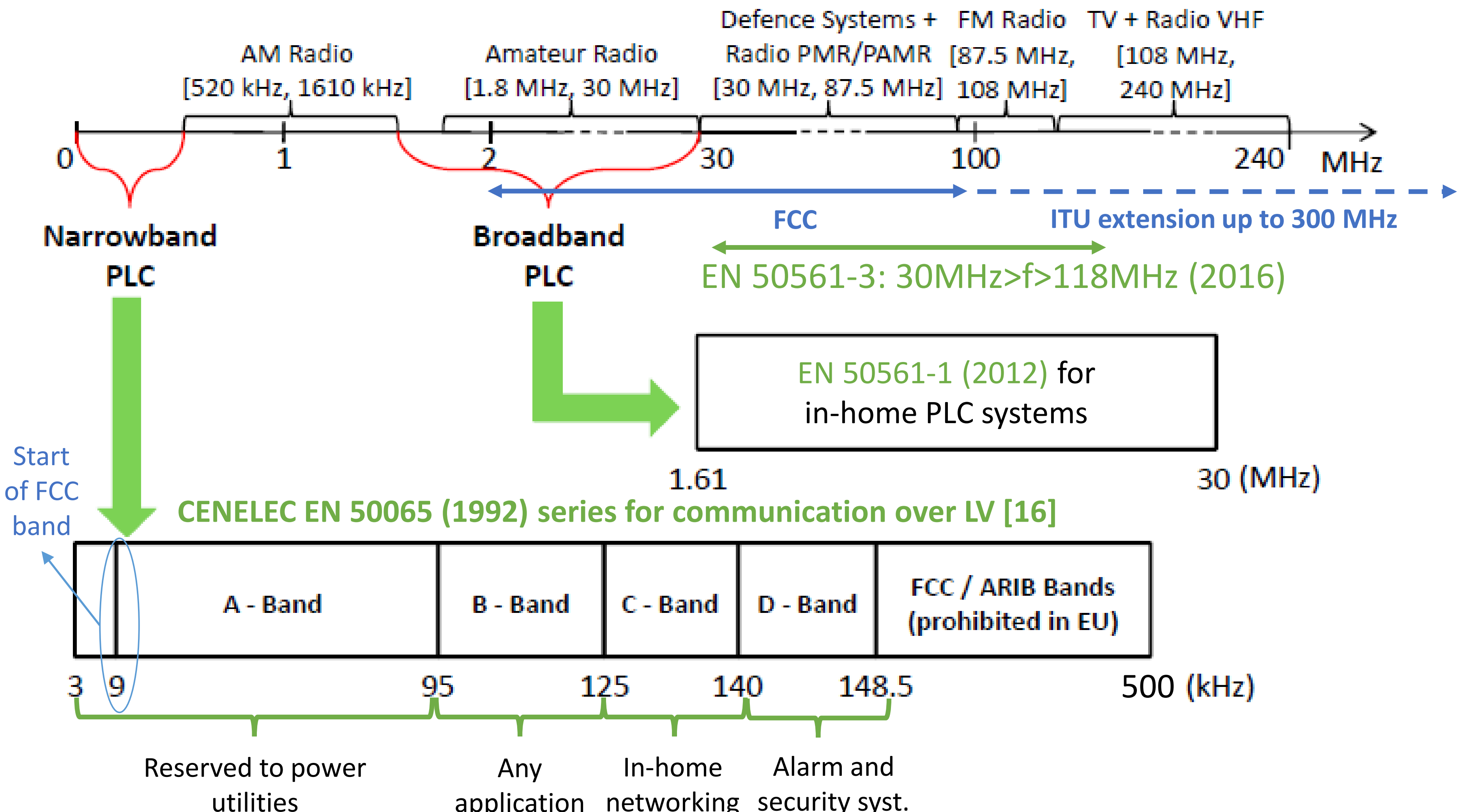

Figure modified from [1]: A. Tonello et al., 'Power Line communications for the smart grid', Tutorial at IEEE SmartGridCom2011

In force communication standards for HDR-NB-PLC and BB-PLC

- NB-PLC (year of first standard release):

IEEE 1901.2 (2013)	Smart things, In-vehicule
G3-PLC (Alliance – 2011) → ITU-T G.9903 (2012)	Smart things, In-vehicule
PRIME (Powerline Related Intelligent Metering Evolution) (Alliance – 2009) → ITU-T G.9904 (2012)	Smart things
G.hnem ITU-T G.9902 (2011 – PHY and DLL)	Smart things, In-vehicule

Modified from [17]: R. M. de Oliveira et al., 'Medium Access Control Protocols for Power Line Communication: A Survey', IEEE Communications Surveys & Tutorials, 2018

In force communication standards for HDR-NB-PLC and BB-PLC

- BB-PLC (year of first standard release):

HomePlug 1.0 (2001)	Home Area Networks
HomePlug AV (2005)	Multimedia
HomePlug GreenPHY (2010)	Smart things, In-vehicule, multimedia
HomePlug AV2 (2012)	Multimedia
ITU G. hn (2010)	Smart things, In-vehicule
ITU G. hn MIMO (2011)	Home networks
IEEE 1901 (2010)	Smart things, In-vehicule, multimedia

Modified from [17]: R. M. de Oliveira et al., 'Medium Access Control Protocols for Power Line Communication: A Survey', IEEE Communications Surveys & Tutorials, 2018

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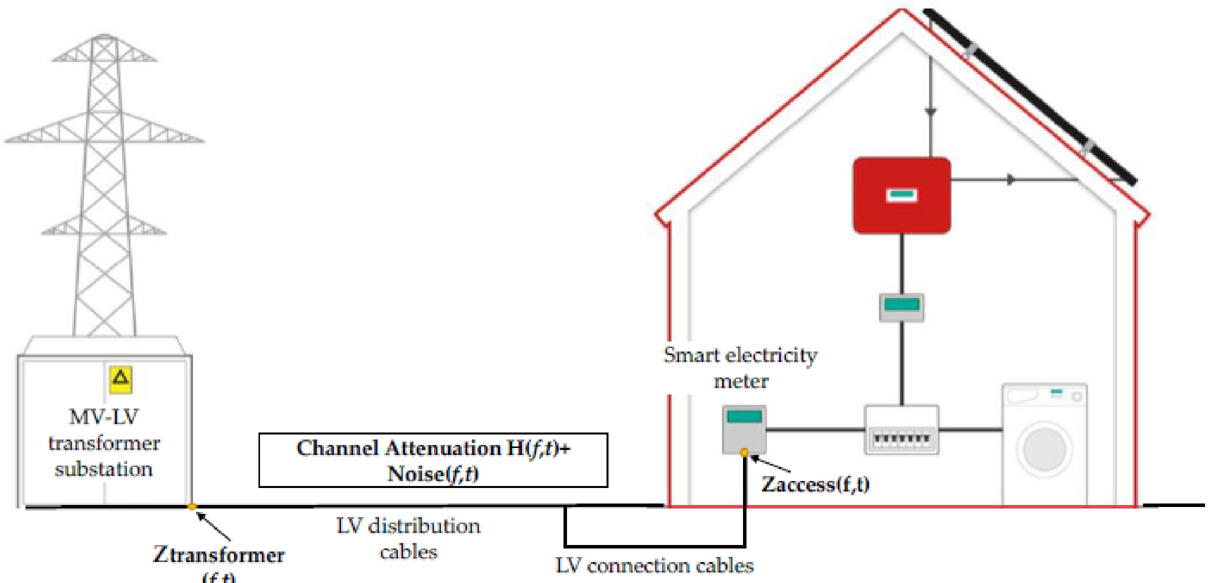
What is different with this communication medium? Case of LV network



Quality of the NB-PLC in the LV networks depends on 3 characteristics:

1. impedance discontinuities,
2. attenuation of the communication channel,
3. noise levels generated by distribution cables.

Figure from [4]: I. Elfeki et al., 'Characterization of Narrowband Noise and Channel Capacity for Powerline communication in France', Energies 2018, 11, 3022, MDPI

- Impedance not known and varying with time → echoes and VSW
  - Multipath propagation & fading → Intersymbol Interference → equalization problems
- Cable not shielded → cable = antenna
  - TX antenna → EMC problems
  - RX antenna → highly noisy communications channel
- Harsh transmission propagation environment!

Why a channel transfer function with fading?

- Typical LV network with unmatched and varying loads → reflections

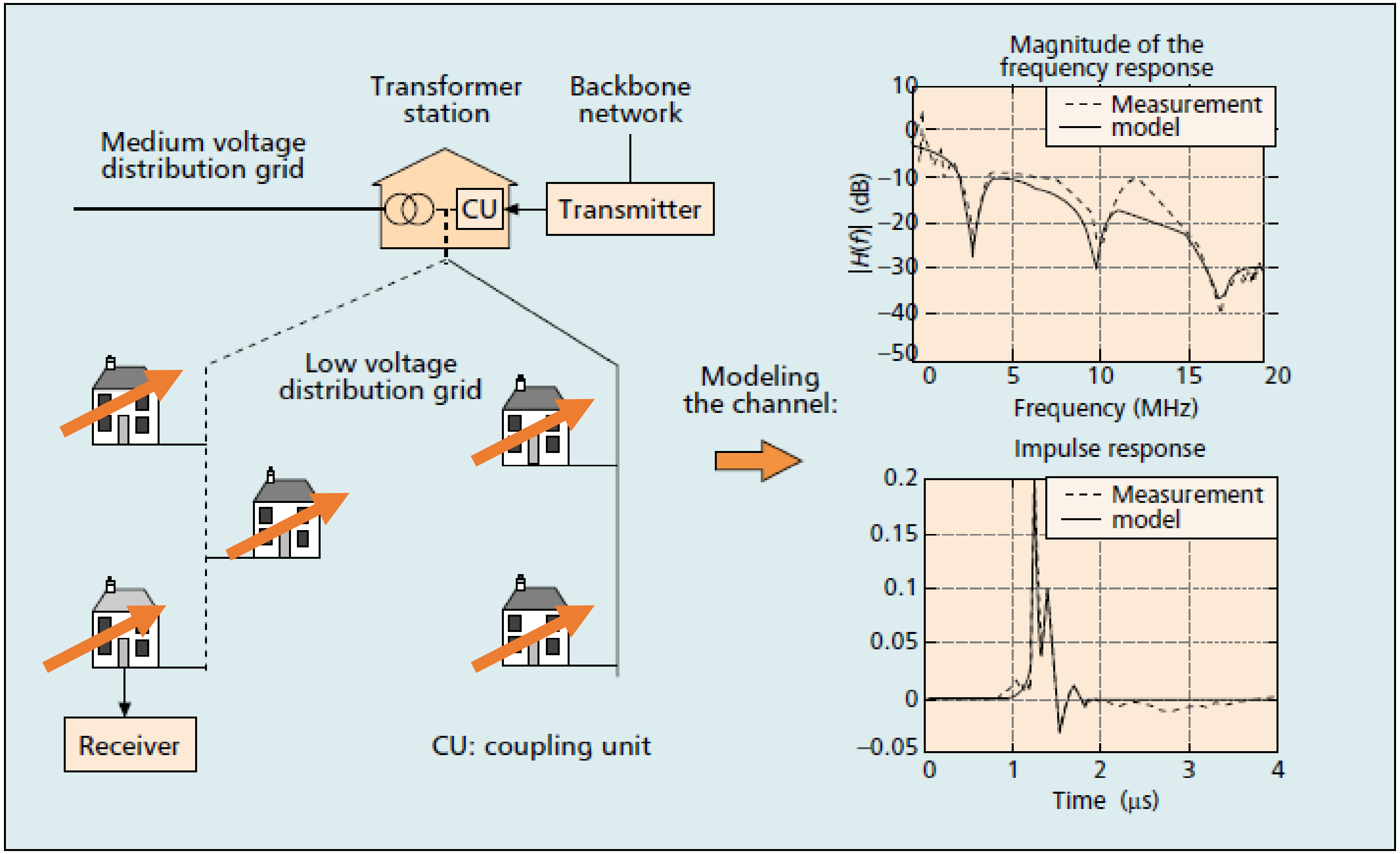
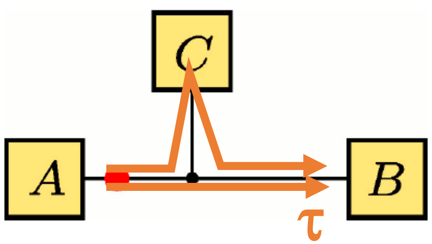
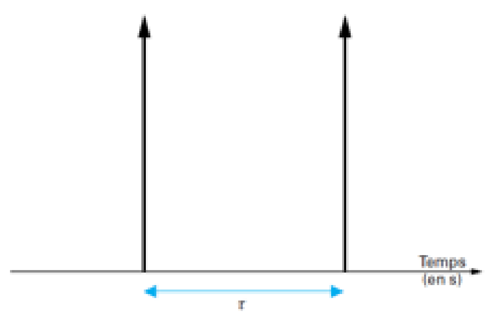


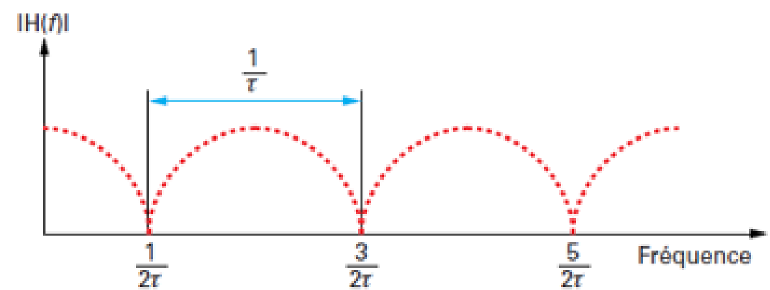
Figure modified from [11]: M. Götz et al., 'Power Line Channel Characteristics and Their Effect on Communication System Design', IEEE Communications Magazine, April 2004, pp, 78-86

The network channel exhibits:

- High attenuation with frequency dependancy
- Multipath propagation due to discontinuities and unmatched loads → Frequency selective fading like wireless channels







- $h(\tau) = \delta(t) + \delta(t-\tau)$
- $H(f) = 1 + e^{-j2\pi f\tau} = e^{-j\pi f\tau}\left(e^{j\pi f\tau} + e^{-j\pi f\tau}\right) = e^{-j\pi f\tau}(2\cos(\pi f\tau))$
- $|H(f)| = 4\cos^2(\pi f\tau)$ which zeroes for $f = \frac{1}{2\tau}, \frac{3}{2\tau}, \frac{5}{2\tau}, \dots$
- Those correspond to a series of holes in the transfer function modulus, spaced by $\Delta f = \frac{1}{\tau}$

There are 3 different power line channel noise scenarios

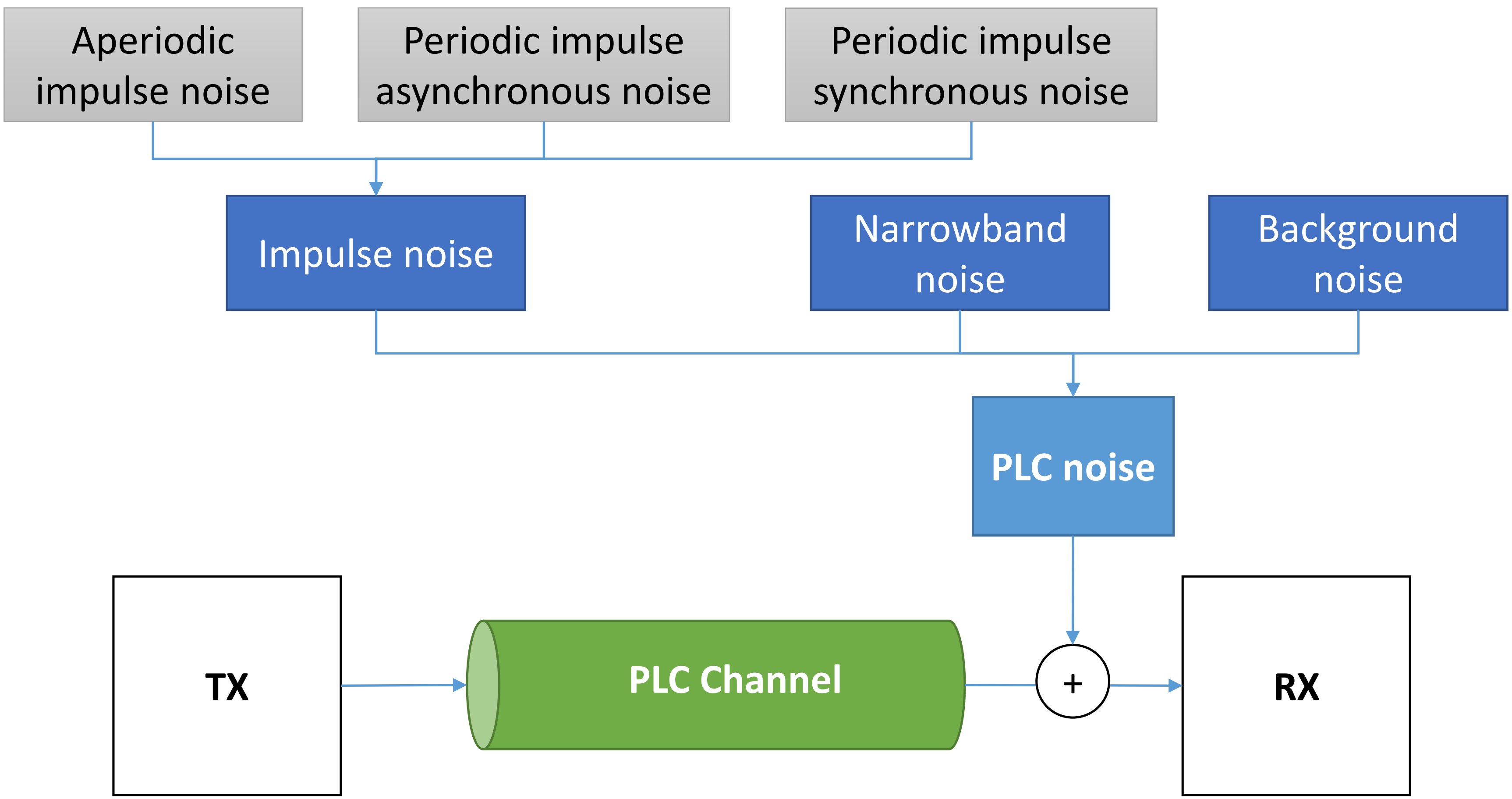
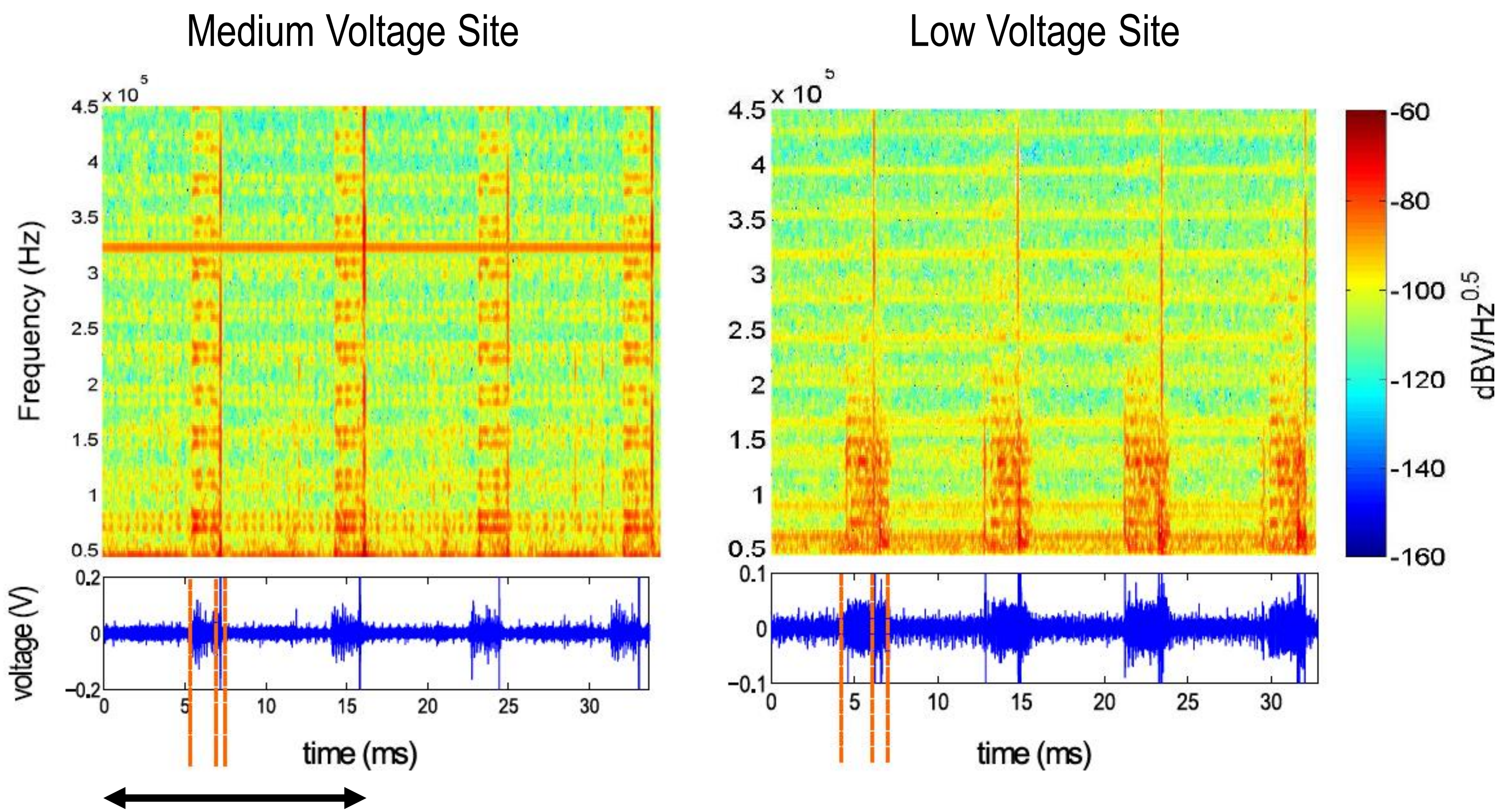


Figure modified from: Ndjiongue, A. R., and H. C. Ferreira. "Power Line Communications (PLC) Technology: More Than 20 Years of Intense Research", to be published in Transactions on Emerging Telecommunications Technologies (Wiley), January 2019

Cyclostationary (periodic impulse related to the main)



From 'Smart Grid Communications', B. Evans, 14/12/2014, http://users.ece.utexas.edu/~bevans/projects/plc/talks/PLCTalkAug2013.pptx

Noise PSD

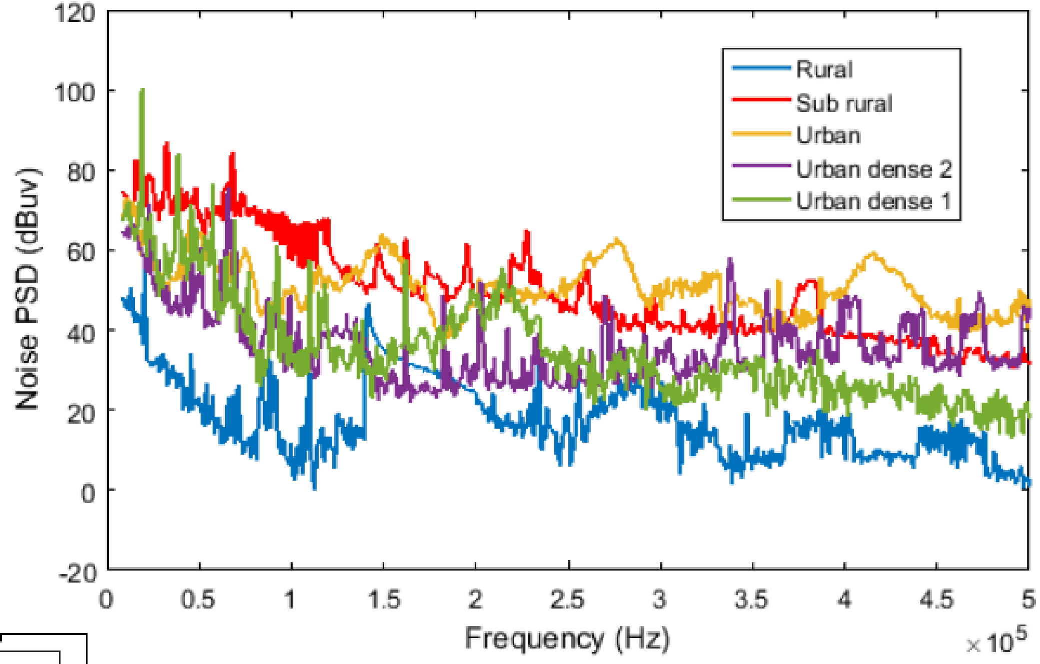


Figure 9. Noise PSD at the customer side at the smart electricity meter.

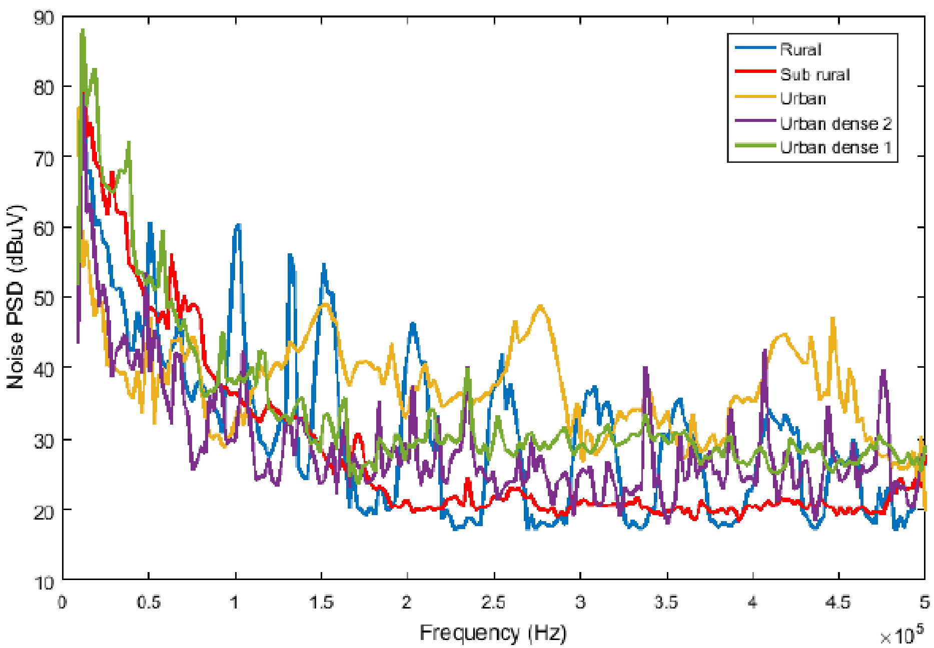


Figure 8. Noise power spectral density (PSD) in the transformer substation.

From [4]: I. Elfeki et al., 'Characterization of Narrowband Noise and Channel Capacity for Powerline communication in France', Energies 2018, 11, 3022, MDPI

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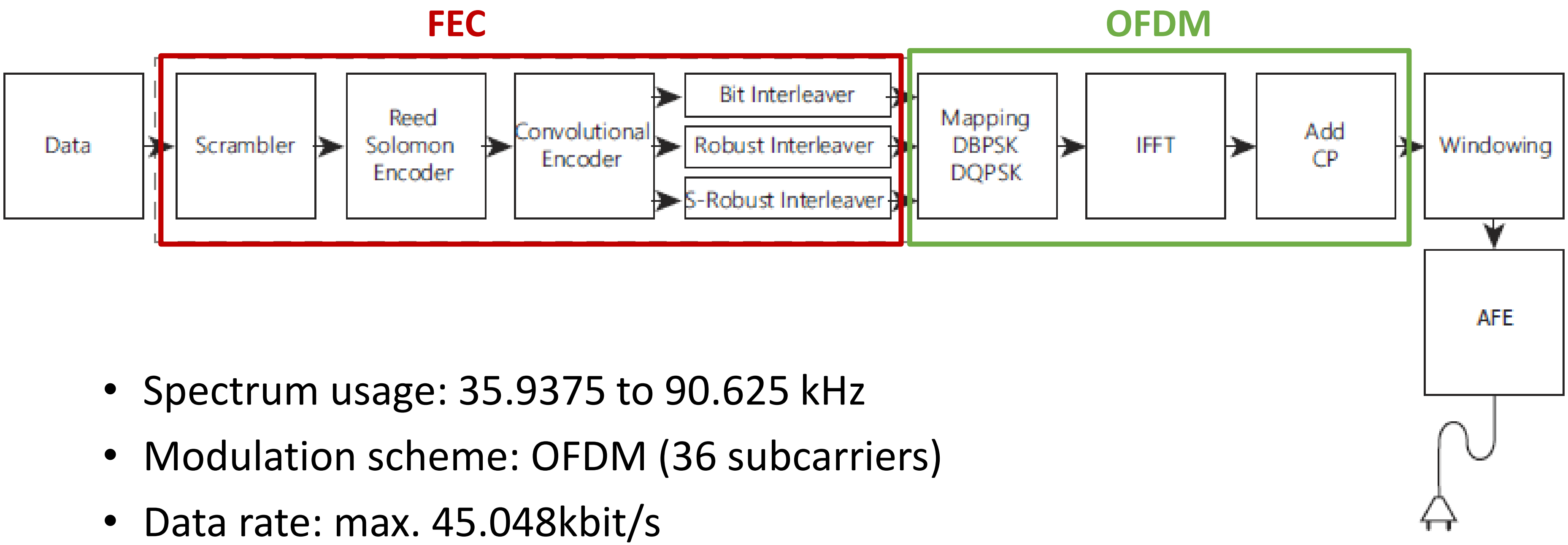
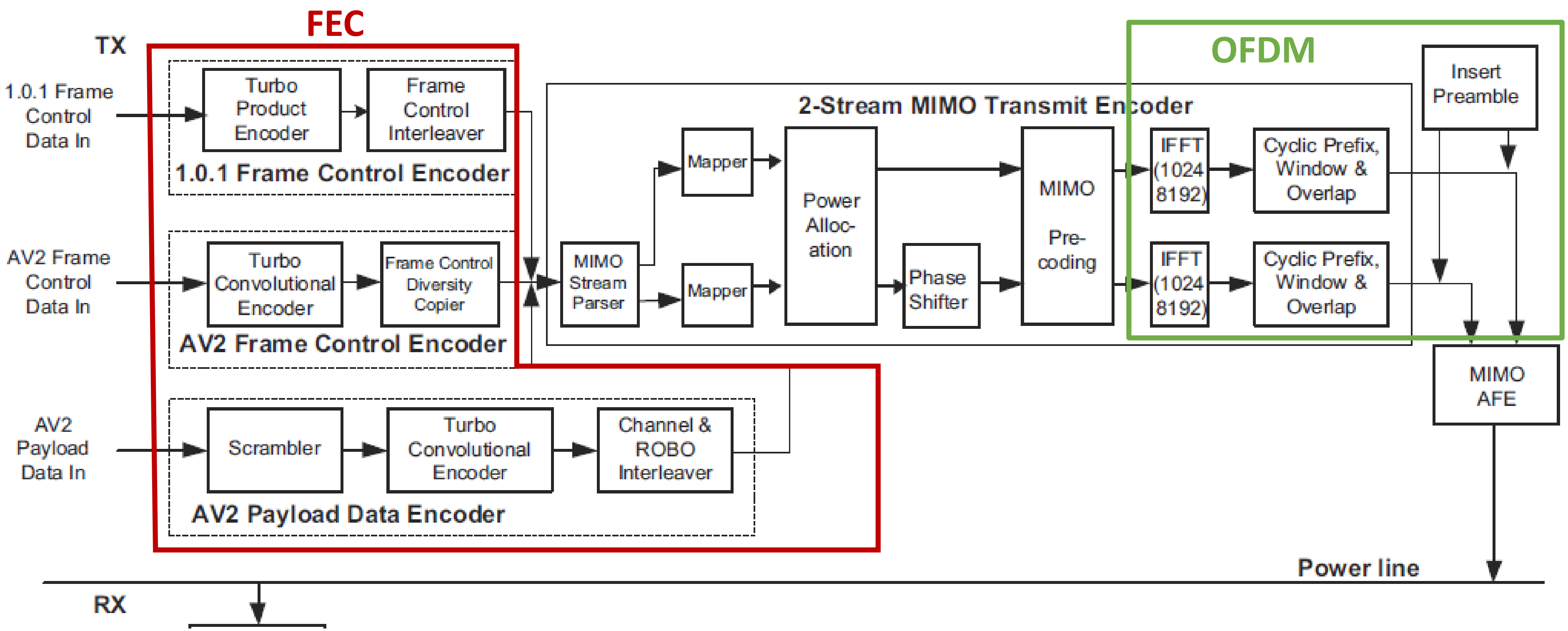
Bloc schematics of NB-PLC - e.g. G3-PLC TX



- Spectrum usage: 35.9375 to 90.625 kHz
- Modulation scheme: OFDM (36 subcarriers)
- Data rate: max. 45.048kbit/s
- Subcarrier modulation: BPSK, QPSK, 8PSK
- FEC: RS, convolutional code and repetition code + interleaving

Bloc schematics of BB-PLC - e.g. HomePlug AV2TX

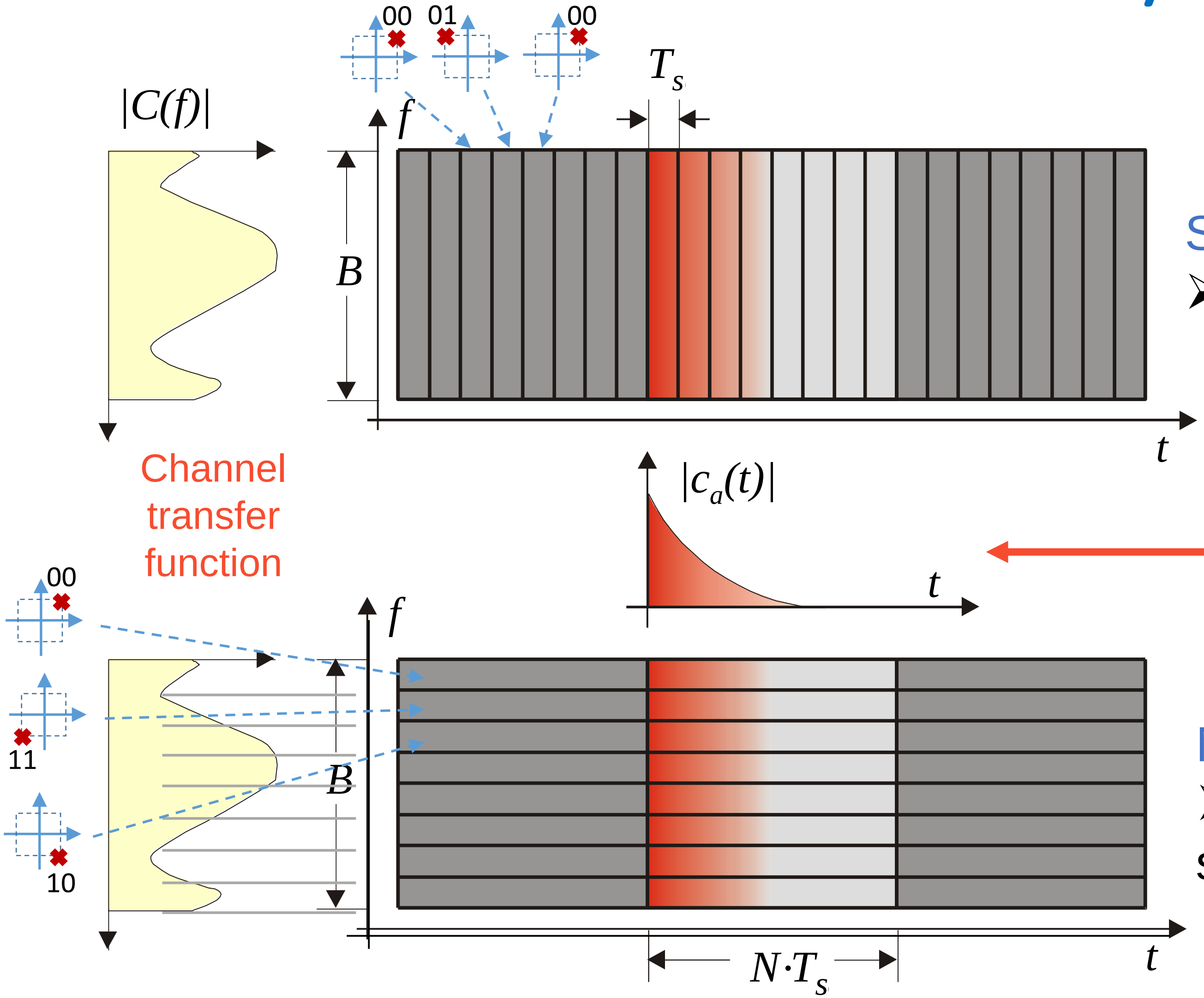


- Spectrum usage: 1.8 to 86.13 MHz
- Modulation scheme: OFDM (3455 subcarriers) and 2x2 MIMO (Multiple Input Multiple Output)
- Data rate: 3.7 Mbit/s to max 2024 Mbit/s in some modes
- Subcarrier modulation: BPSK, QPSK, 8PSK, 16- to 4096-QAM + robo

Modulation and signal processing solutions

- Solutions to cope with the harsh propagation environment:
  - OFDM (Orthogonal Frequency Division Multiplexing)
  - Reed Solomon (RS) code
  - Convolutional code
  - Interleaving

OFDM (MCM scheme with orthogonality): splits the data rate into parallel data signals to increase the transmitted symbol duration



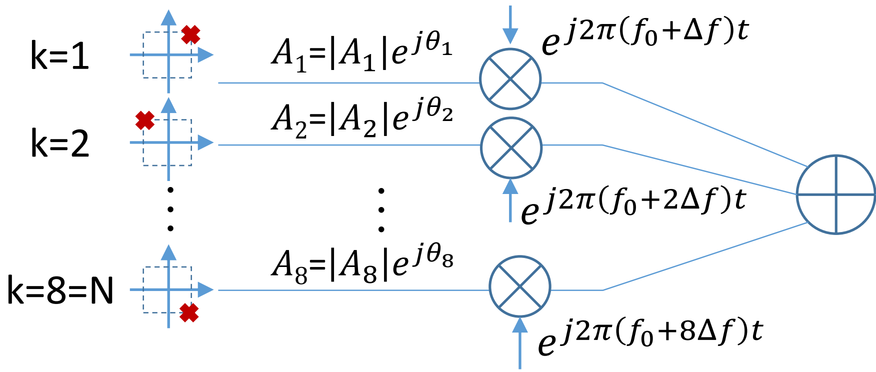
Single Carrier (SC)

- Equalisation problems

Multi carrier (MC)

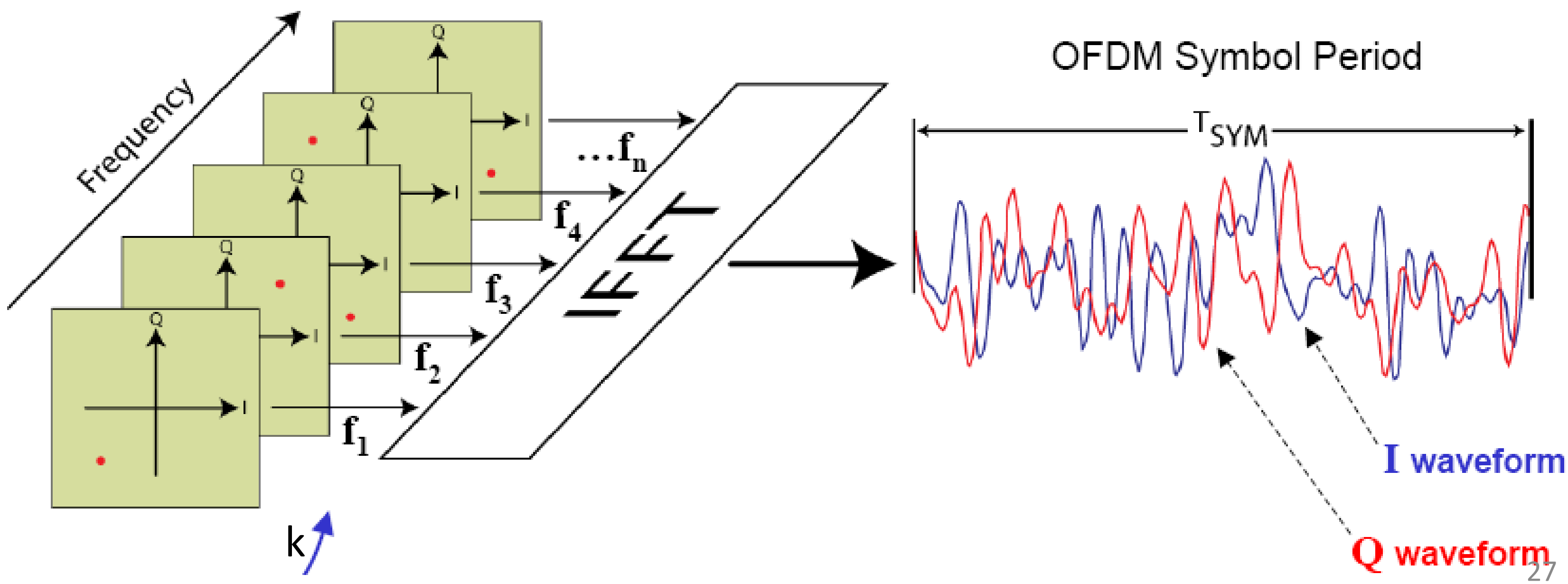
- Sub channels are not selectives

IFFT implementation of OFDM



$$\sum_{k=1}^{N} A_k e^{j\omega_k t} = \sum_{k=1}^{N} A_k e^{j2\pi(f_0+k\Delta f)t}$$

- Looks like an IDFT → IFFT implementation (k is a power of 2)



OFDM – pros & cons

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- High spectral efficiency

- Possibly no need of channel equilization

- Robustness against narrow band co-channel interferers

- Robustness against ISI and fading coming from multipath propagation

- Efficient implementation using IFFT/FFT

- Low sensitivity to time synchronisation problems

−

- Sensitivity to Doppler shift

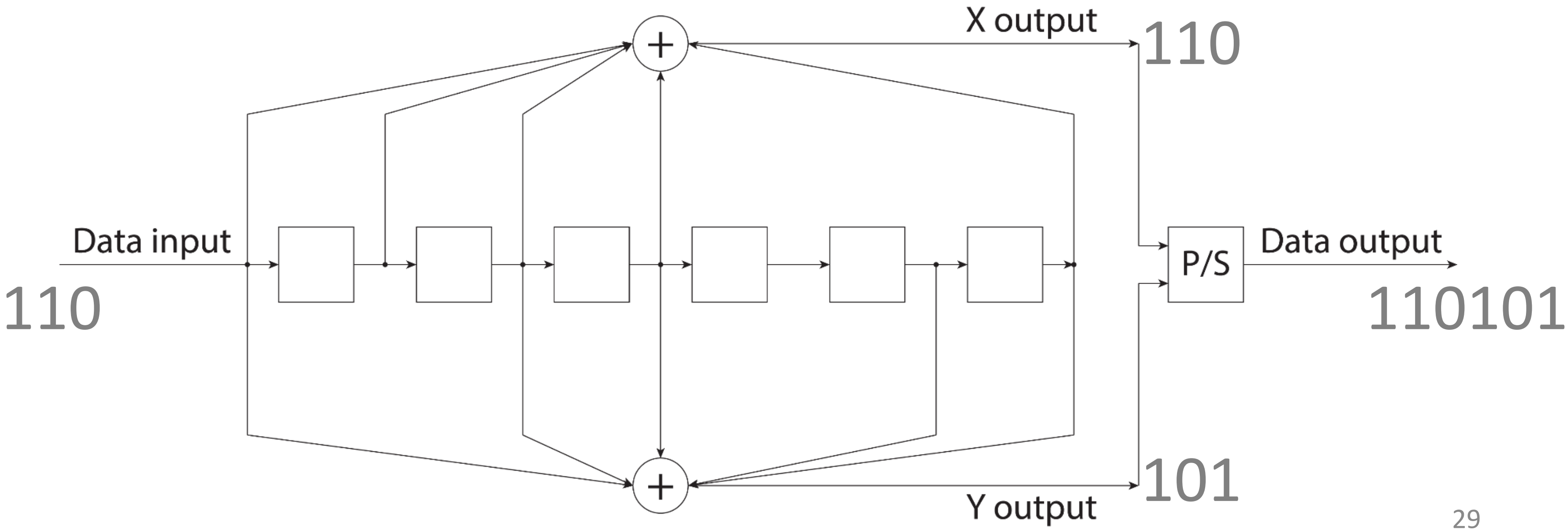
- Sensitivity to frequency synchronisation problems

- High peak to average power ratio (PAPR) – distorsion if amplification

- Need of a cyclic prefix

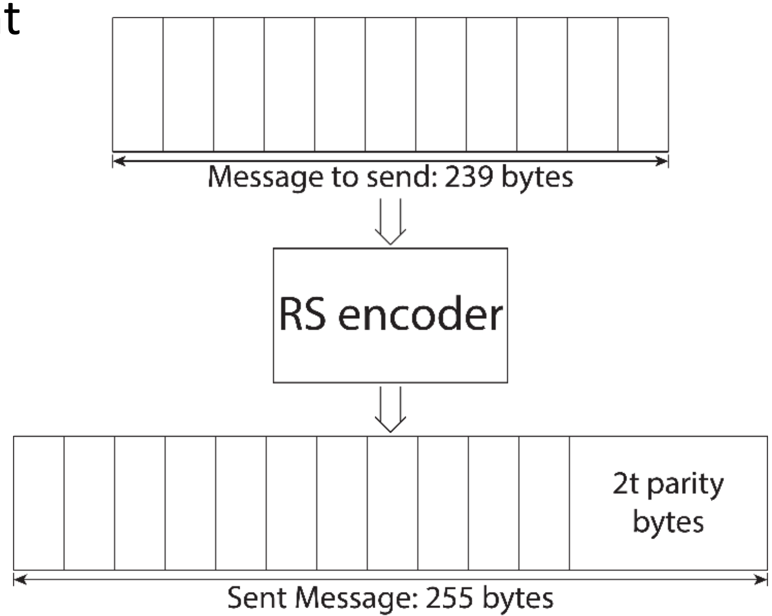
A way to cope with perturbation is using correction codes

- Convolutional code:
  - The convolutional code is a correction code where the added redundant bits are depending on the input of the encoder and their predecessors
  - E.g. G3-PLC convolutional coding - as there are two outputs to the decoder, the bitstream doubles in size thus adding redundancy and robustness



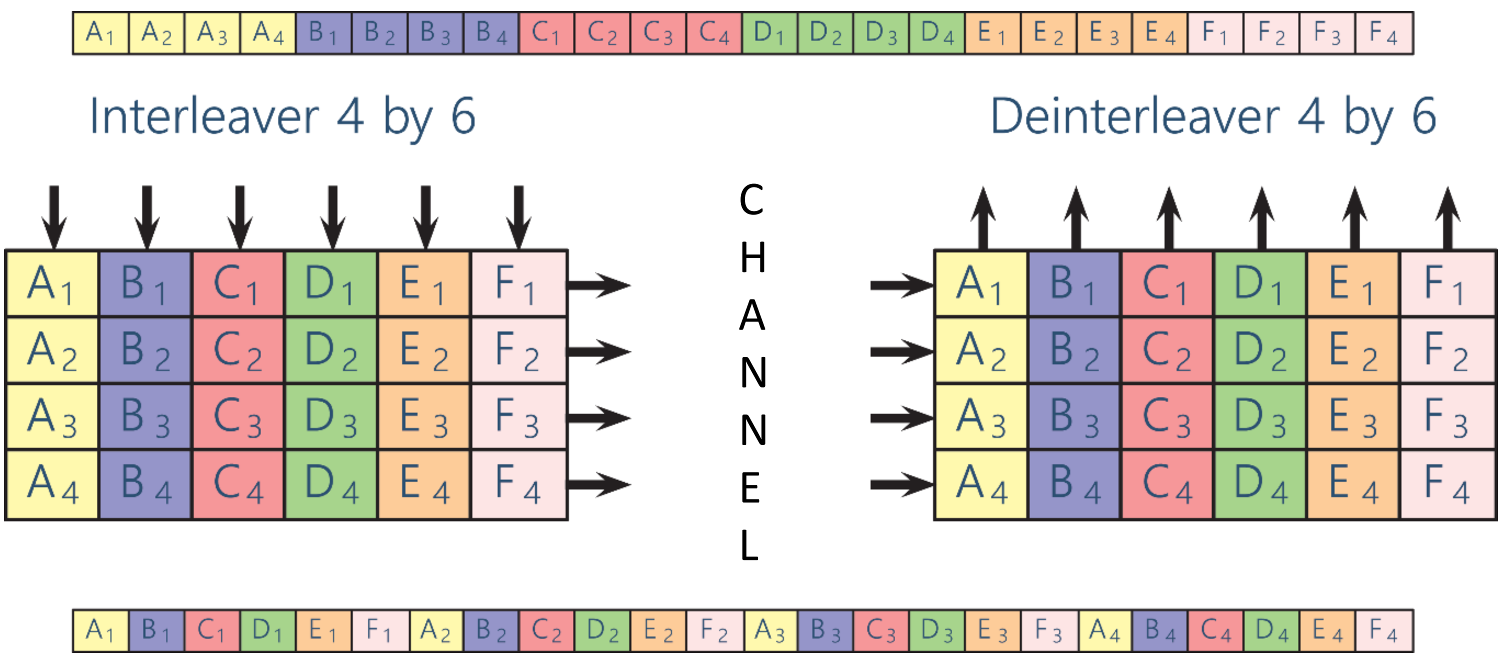
Reed-Solomon corrects bytes not bits

- Reed-Solomon:
  - Reed-Solomon is a block encoder, that means that it can protect a defined number of bits by adding redundant bits of information
  - E.g, the G3-PLC encoder is a RS(255,239)
    - It can detect up to 16 erroneous bytes
    - It can correct up to 8 erroneous bytes
  - RS codes are very well suited for burst errors (because they correct bytes not bits)
  - By combining convolutional code with RS code, the resulting error coding scheme is more efficient

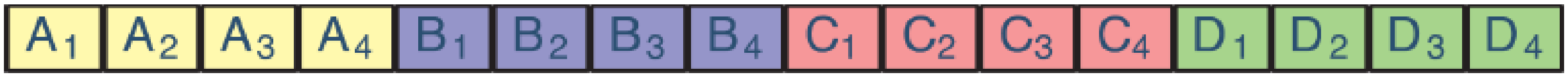


Interleaving to distribute information in time and/or frequency to improve the performances of correction codes

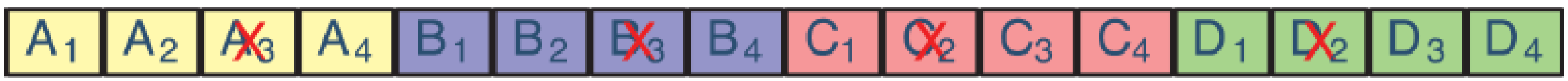
- Typically symbols are entered into the interleaver buffer by columns and removed by rows. They are spread in time and/or in frequency (subcarriers)
- The interleaver block is used to prevent:
    - a burst error (impulse noise) that corrupts a few consecutive OFDM symbols
    - a frequency deep fade that corrupts a few adjacent frequencies for a large number of OFDM symbols



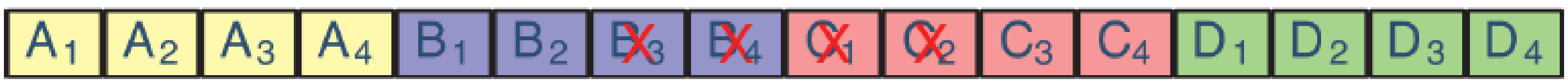
- Original sequence composed by 4 coded words



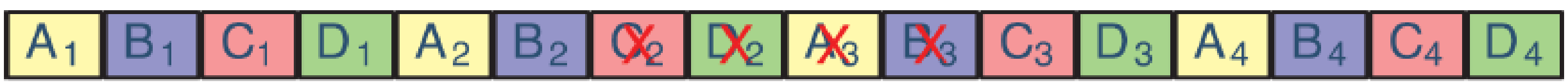
- Correction is possible with one error per block



- When burst errors occurs, the correction code doesn’t work anymore



- But by using the interleaver, the errors are distributed



- The correction code is functioning correctly

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Time-based MAC (Medium Access Control) methods for NB-PLC and BB-PLC standards

NB

IEEE 1901.2 (2013)	CSMA/CA
G3-PLC (Alliance – 2011) → ITU-T G.9903 (2012)	CSMA/CA
PRIME (Powerline Related Intelligent Metering Evolution) (Alliance – 2009) → ITU-T G.9904 (2012)	CSMA/CA
G.hnem ITU-T G.9902 (2011 – PHY and DLL)	CSMA/CA

BB

HomePlug 1.0 (2001)	CSMA/CA
HomePlug AV (2005)	CSMA/CA, TDMA
HomePlug GreenPHY (2010)	CSMA/CA
HomePlug AV2 (2012)	CSMA/CA, TDMA
ITU G. hn (2010)	CSMA/CA, TDMA
ITU G. hn MIMO (2011)	CSMA/CA, TDMA
IEEE 1901 (2010)	CSMA/CA, TDMA

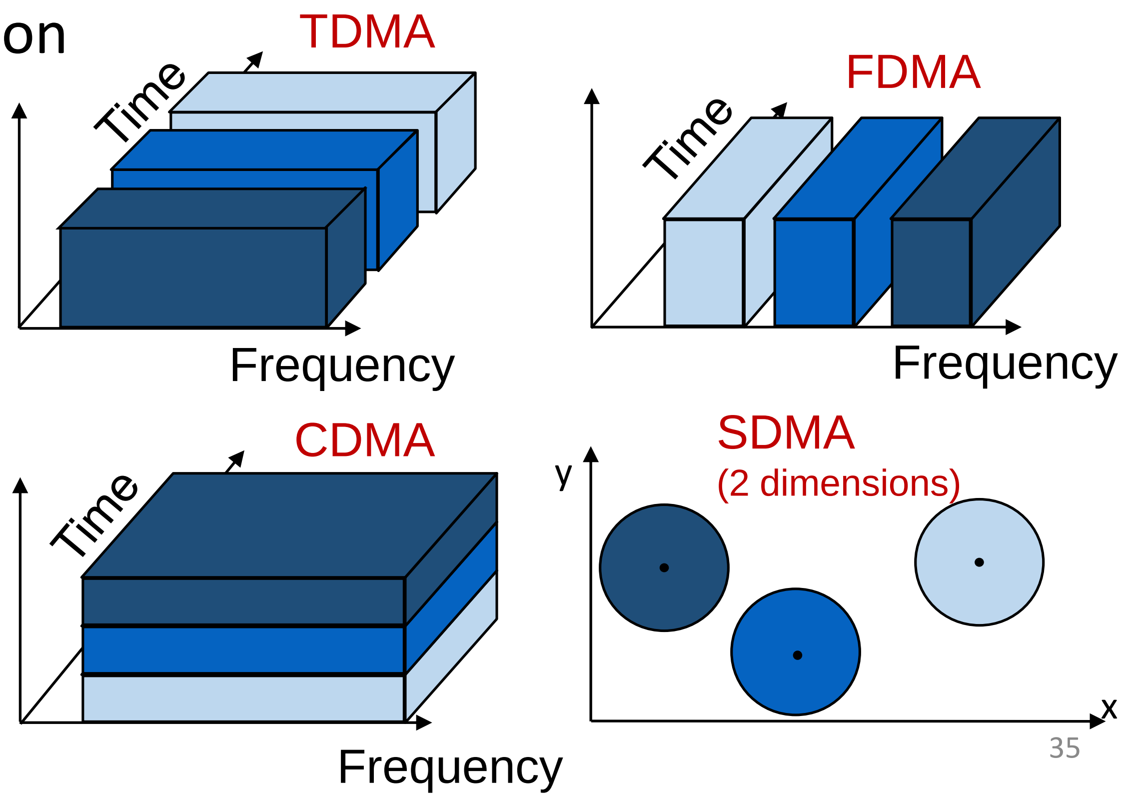
CSMA/CA = Carrier Sense Multiple Access/Collision Avoidance

TDMA = Time Division Multiple Access

Modified from [17]: R. M. de Oliveira et al., 'Medium Access Control Protocols for Power Line Communication: A Survey', IEEE Communications Surveys & Tutorials, 2018

TDMA – all objects are sharing the access to the medium in time in a deterministic way

- To avoid collision between objects, the access method defines ‘when’ and for ‘how long’ an object may send its signal so it gets the channel alone for an amount of time
- Delay of transmission is mastered
- But:
  - a coordinator is needed
  - precise synchronisation is needed



Note: there are
- Guard intervals (TDMA)
- Guard bands (FDMA)
- Guard spaces (SDMA)

CSMA/CA - all objects are sharing the access to the medium in time in a random way

- Contention-based (≈competition) access method
- No need of a central coordinator
- Major steps:
  1. The object listen to know if the channel is free (listen before talking)
  2. If the channel is free:
     - The object sends its data and waits for an ACK
     - If the ACK is not coming, the object considers there has been a collision and reset its packet of data after a random time that has a maximum value
  3. If the channel is not free – 2 methods:
     - The object continues to listen to the channel and sends its packet: ASAP (persistent CSMA), after a random time (backoff algorithm) (CSMA/CA)

     OR

     - The object stops listening and restarts to listen to the channel after a random waiting time (non persistent CSMA)
- The delay of transmission is not constant

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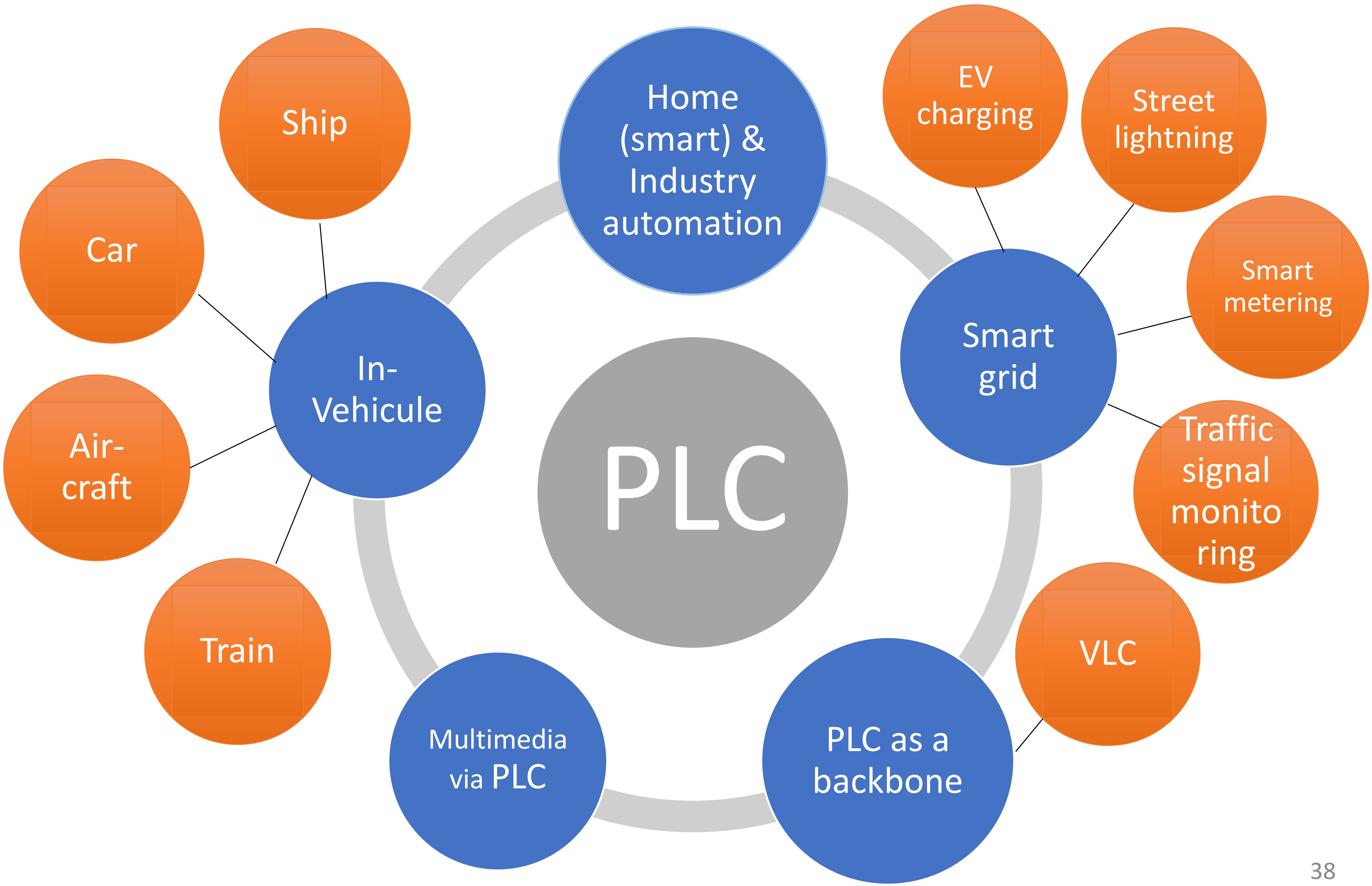
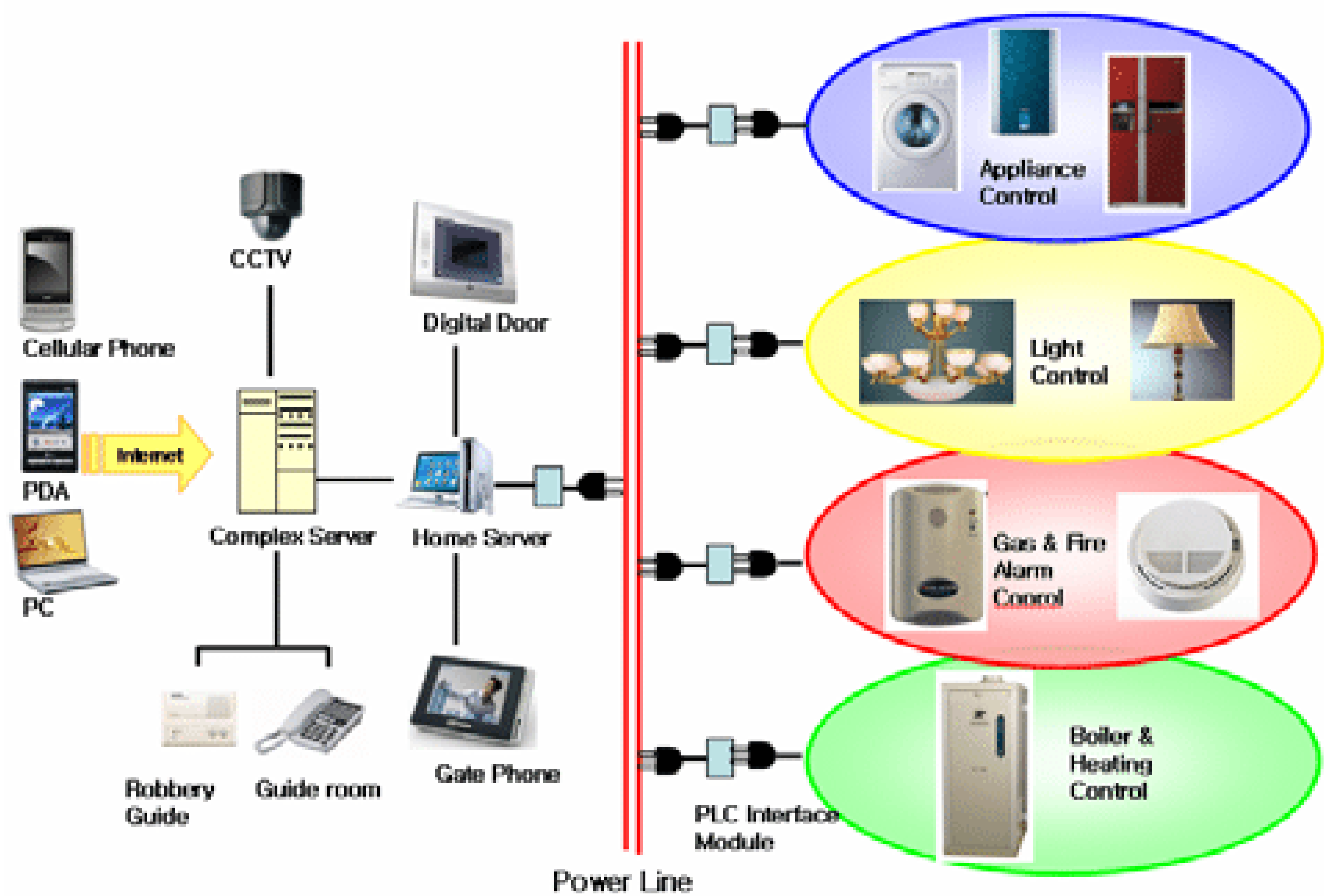
PLC applications

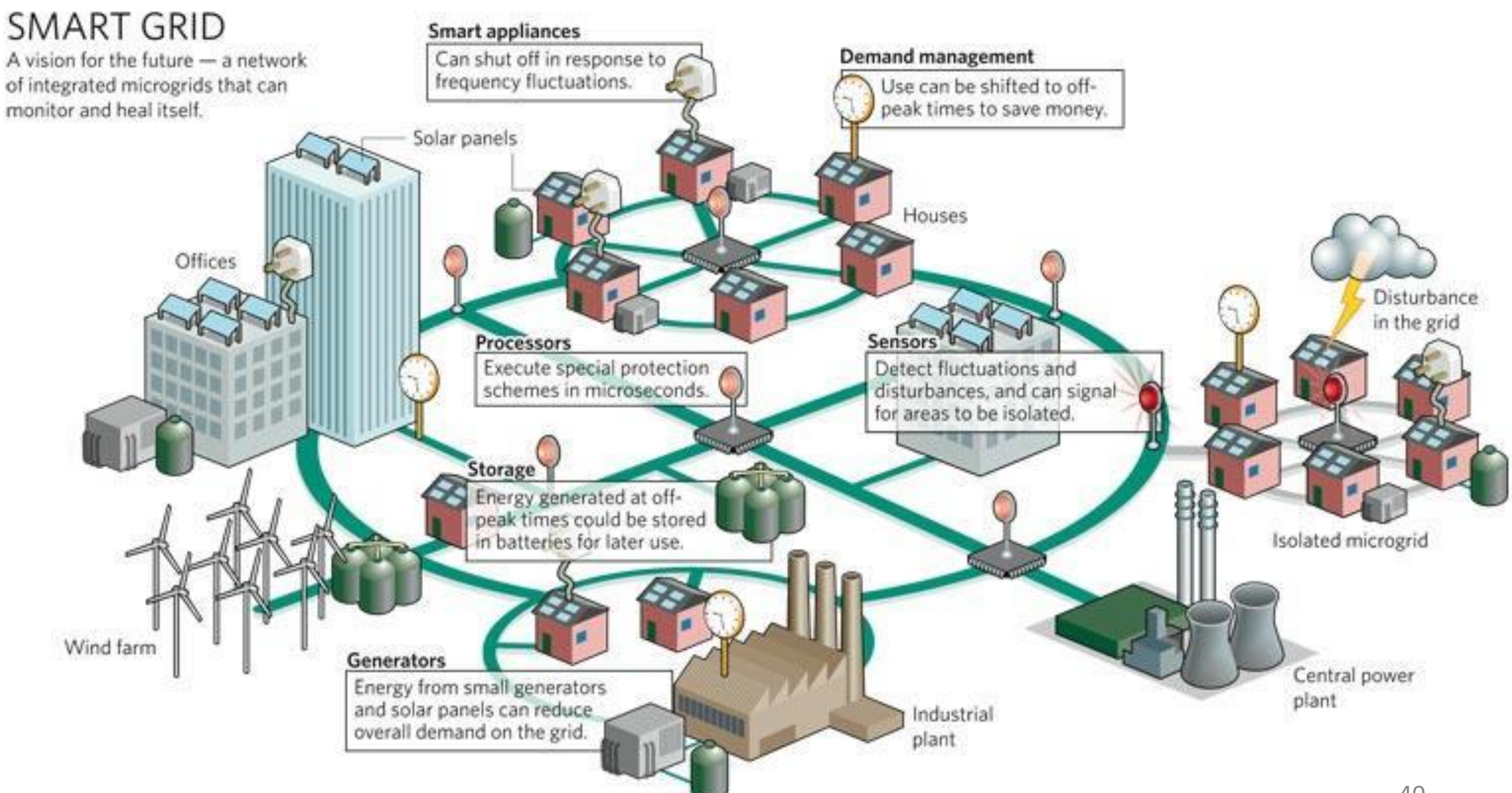


Industry and home automation



From https://www.google.be/search?q=home+automation+power+line&hl=fr&tbm=isch&source=lnms&sa=X&ved=0ahUKEwj0ta-_mMngAhXKyaQKHaRxA58Q_AUICigB&biw=1366&bih=689&dpr=1#imgrc=vVH-Lkuc-Tnw2M:&spf=1550627222275

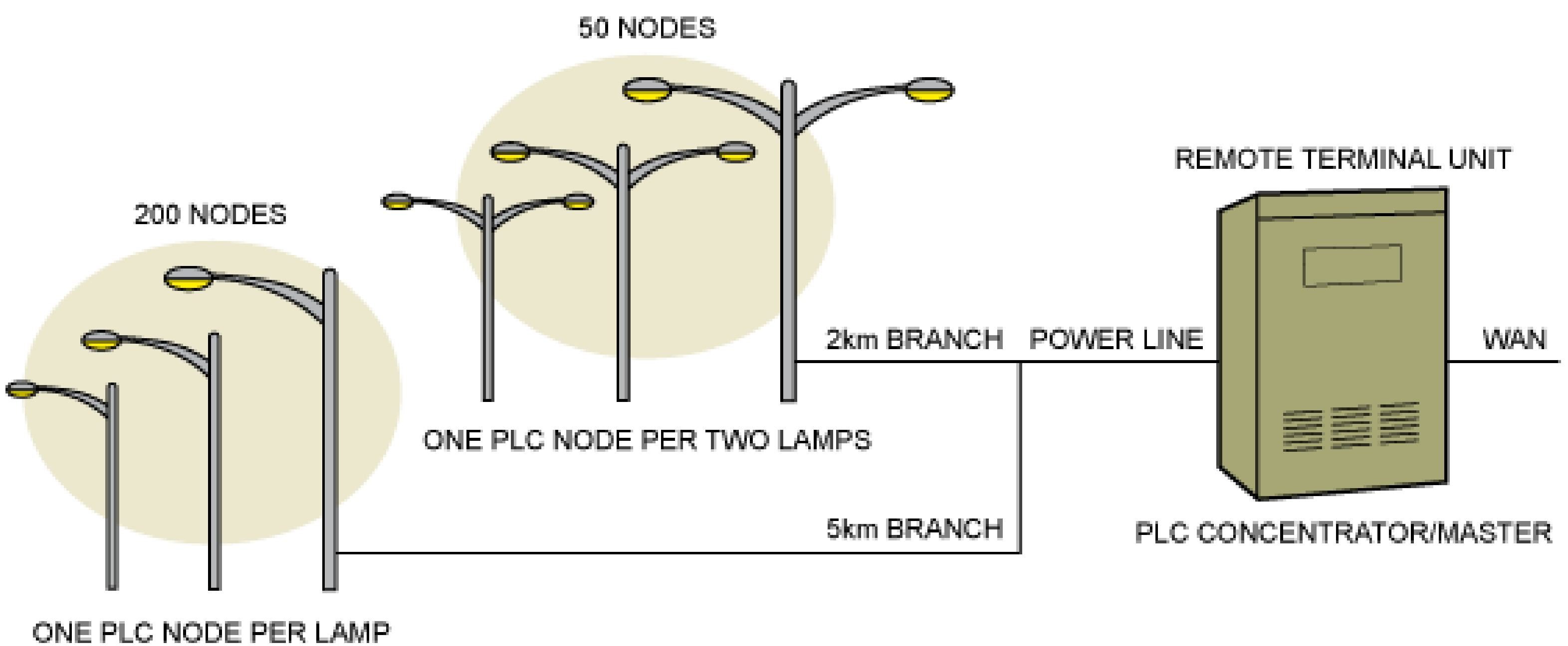
Smart grid = power grid + intelligence & com
What kind of services communication can enable?



From https://www.engineersgarage.com/sites/default/files/1_29.jpg

Smart grid applications

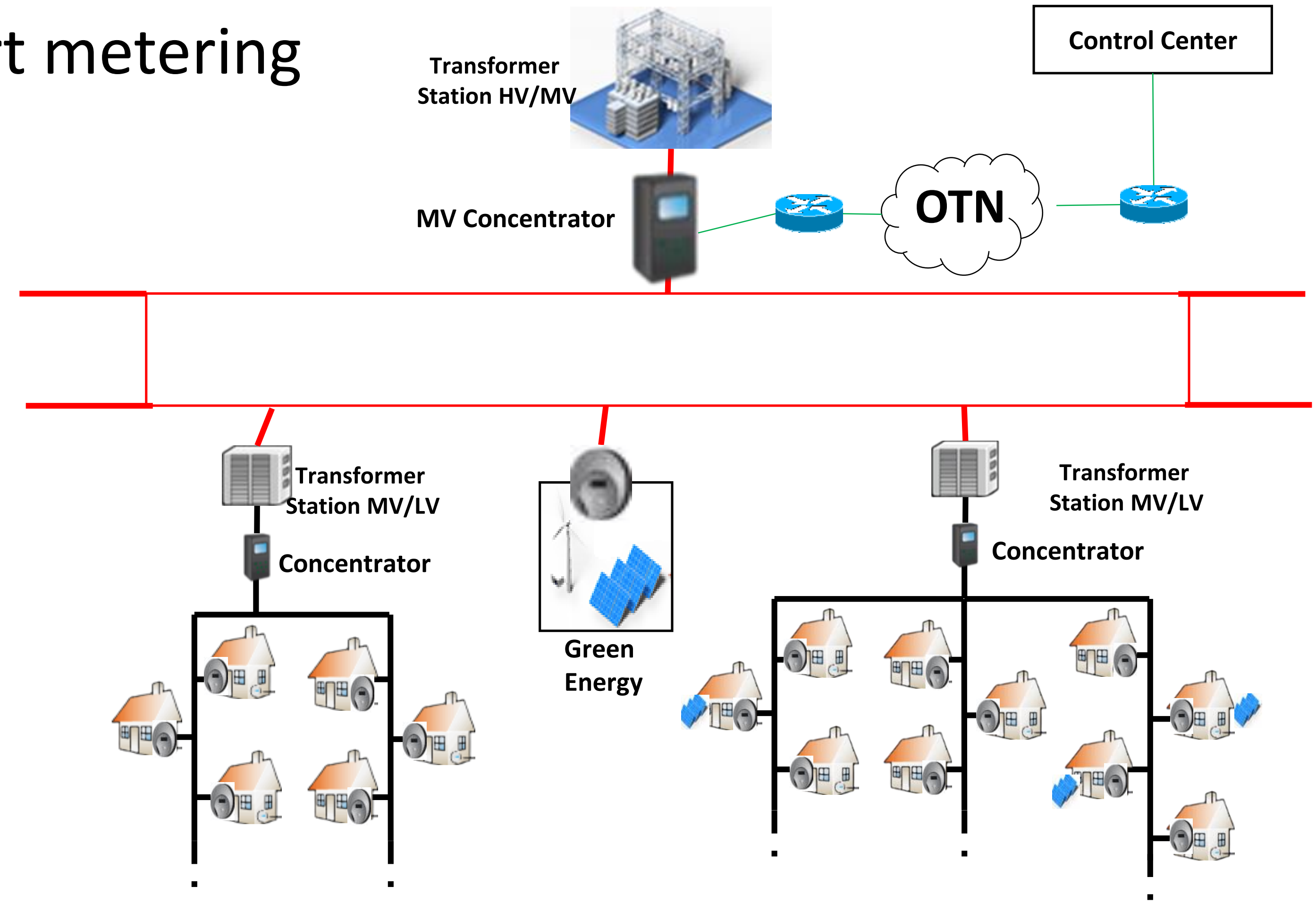
- Typical automated street light network topology



From [20]: Powerline Communication for Street Lighting Automation', application note 5347, Maxim Integrated inc., https://www.maximintegrated.com/en/app-notes/index.mvp/id/5347

Smart grid applications

- Smart metering



In-Vehicule: PLC in cars

- Advantages of PLC:
  - more and more electronics systems in cars
  - pressure on establishing monitoring and automation → communication
  - reuse of electricity wires (cost, weigth and space benefits)
  - electrical vehicules (Evs) are coming → communication for battery management

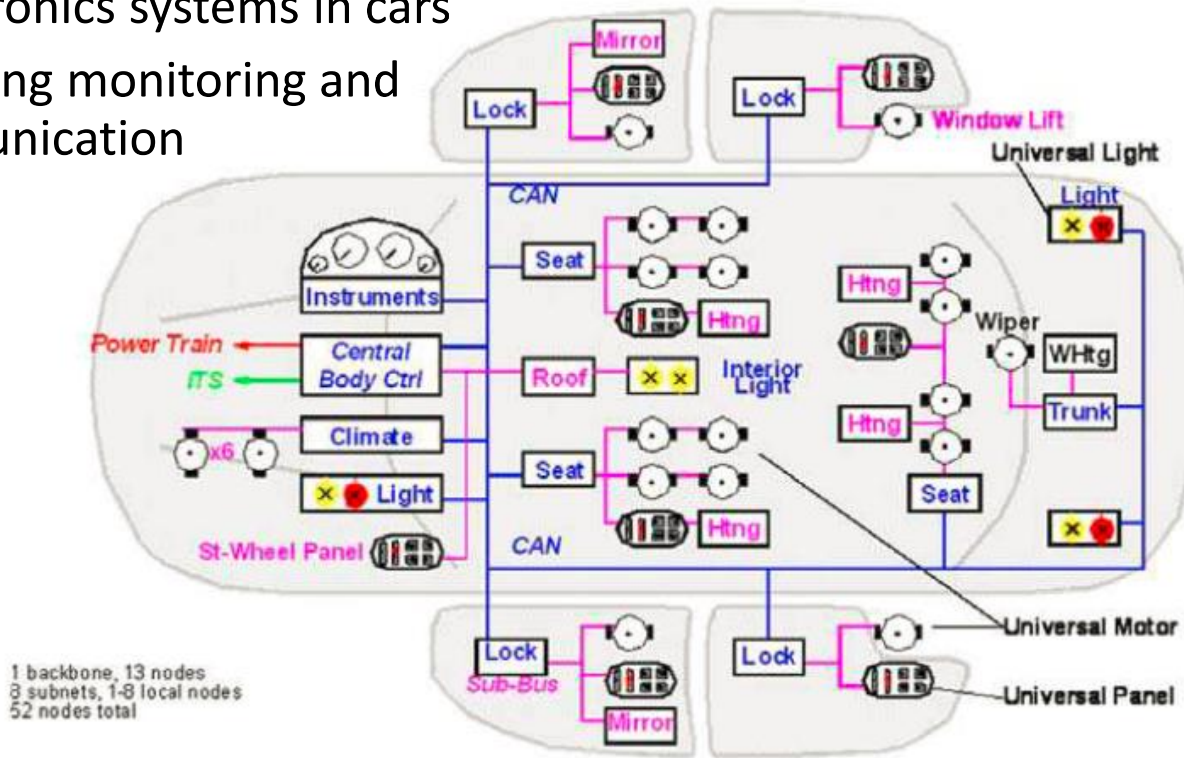
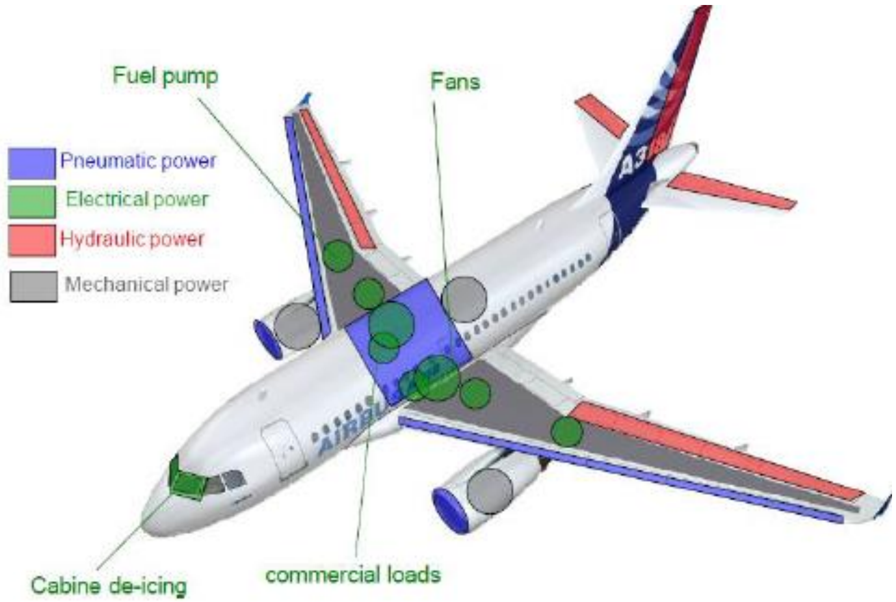


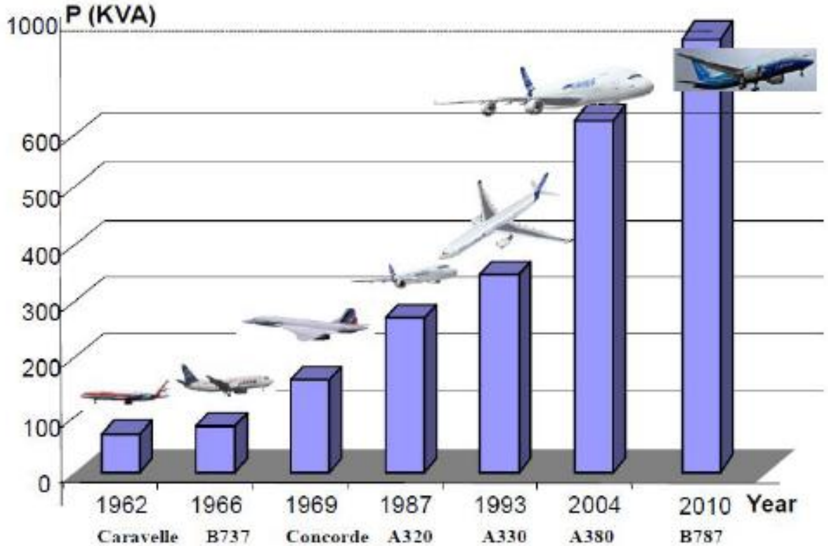
Fig. 1. Network architecture (from http:// www.freescale.com)

From [21]: F. Nouvel et al., 'Experiments of In-Vehicule Power Line Communications', Intech Open, https://www.intechopen.com/books/advances-in-vehicular-networking-technologies/experiments-of-in-vehicle-power-line-communications

In-Vehicule: PLC in planes (aircrafts and spacecrafts)

- From the upcoming of Airbus A380 and Boeing 787, the concept of MEA (More Electrical Aircraft) is developing
  - MEA = replacing at most hydrolic systems by electrical systems
  - to reduce the aircraft weight + easiness of maintenance



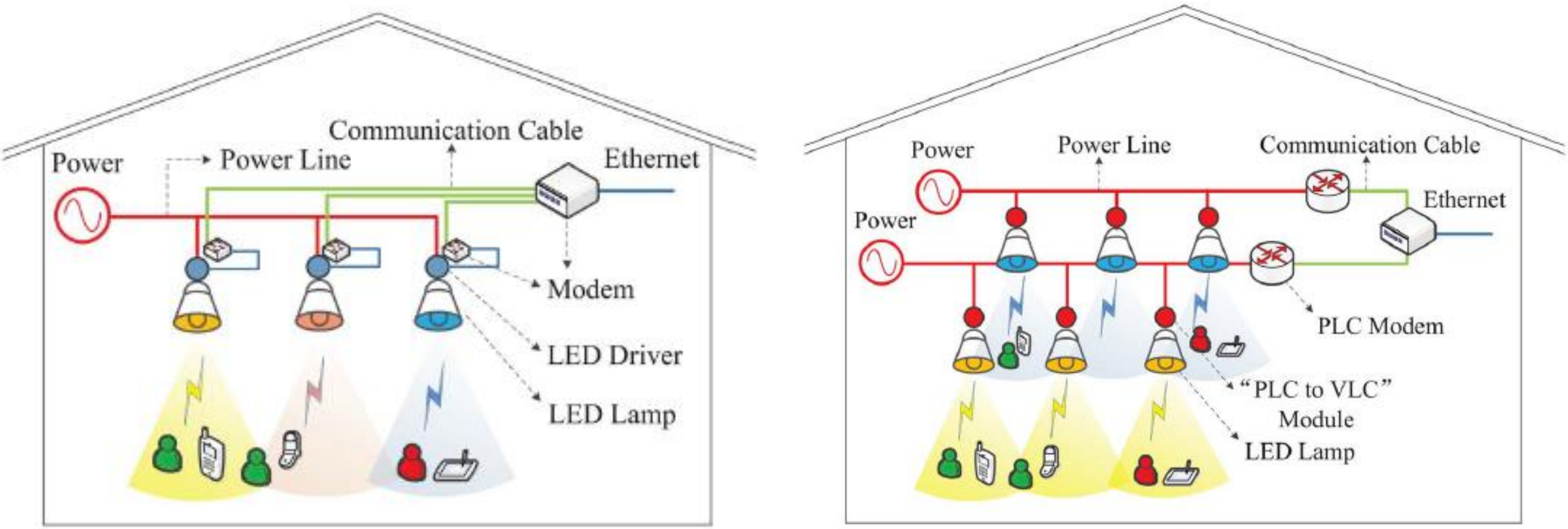


From [22]: Navish Lallbeeharry, 'Réseaux d'énergie Embarqués dans les Systèmes de Transport : Communication et Diagnostic Passif par Courant Porteur en Ligne (CPL)', PhD thesis, Lille University, IEMN, 2018

In-Vehicule: PLC in planes (aircrafts and spacecrafts)

- At the beginning, communications busses where used
  - ex: CAN (Controller Area Network) bus – max. 1Mbit/s
- Faisability of PLC high bit rate communications in aircraft has been established
- But = classical homeplug is not EMC (ElectroMagnetic Compatiblity) compatible with the aircraft environment → 'taylored-made' PLC

PLC as backbone – together with VLC (Visual Light Communications)/LiFi



From [18]: J. Song et al., 'An indoor broadband broadcasting systemBased on PLC and VLC', IEEE Transactions on Broadcasting, 2015, vol. 61, no 2, pp. 299-308

Outline

- Standards governing PLC technology
- Channel & noise models & characteristics
- Modulation and processing for PHY PLC
- PLC MAC layer principles
- Application of PLC technology
- PLC modems manufacturing
- Future directions in research

Industrial solutions of PLC standards

- For narrowband PLC (G3-PLC & PRIME):
  - Renesas (https://www.renesas.com/kr/en/solutions/key-technology/connectivity-wired/plc.html),
  - ST (https://www.st.com/en/interfaces-and-transceivers/power-line-transceivers.html?querycriteria=productId=SC923),
  - Maxim (https://www.maximintegrated.com/en/products/comms/powerline-communications.html),
  - Texas Instruments (http://www.ti.com/solution/grid_communications_modules_wired_communications),
  - SemiTech, Semtech, …
- For broadband PLC (homeplug):
  - Broadcom (https://www.broadcom.com/products/broadband/xpon/bcm60500),
  - Qualcomm (https://www.qualcomm.com/products/powerline)
- But also, see: Atheros, Marvell, Sigma, Lantiq, Plugtek, Devolo, Yitran, ….

Outline

- Standards governing PLC technology
- Channel & noise models & characteristics
- Modulation and processing for PHY PLC
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- Issues in implementing PLC applications
- Future directions in research

Trends & Future directions in research

- Some themas of research are quite new:
  - Hybrid PLC/RF communications (5G) [26]
  - Anomaly detection and localization in smart grids using PLC modems [27]
  - Contactless power line communications (WPT) [12]
  - AI in PLC [28]
  - PLC and IoT [29]
- Still a lot to do for:
  - Impulse noise mitigation
  - MAC layer knowledge (combined to PHY)

References

[1] A. Tonello et al., ‘Power Line communications for the smart grid’, Tutorial at IEEE SmartGridCom2011

[2] A. R. Ndjongue et al., ‘Power Line Communications (PLC): More Than 20 Years of Intense Research’, to be published in Transactions on Emerging Telecommunications Technologies, Wiley, 2019

[3] C. Cano et al., ‘State-of-the-art in Power Line Communications:from the Applications to the Medium’, IEEE Journal on Selected Areas in Communications, 2016, vol. 34 (7), pp. 1935-1952

[4] I. Elfeki et al., ‘Characterization of Narrowband Noise and Channel Capacity for Powerline communication in France’, Energies 2018, 11, 3022, MDPI

[5] L. T. Berger et al., ‘MIMO Power Line Communications’, IEEE Communications Surveys & Tutorials, 17(1), 106-124

[6] M. R. Oliveira et al., ‘Medium Access Control Protocols for Power Line Communication: A Survey’, IEEE Communications Surveys & Tutorials (2018).

[7] K. Sharma et al., ‘Power-line communications for smart grid: Progress, challenges, opportunities and status’, Renewable and Sustainable Energy Reviews, Elsevier, 2017, 67, pp. 704–751

[8] L. Lampe, ‘Power Line Communications: Principles, Standards and Applications from multimedia to smart grid’, John Wiley & Sons, 2^{nd} edition, 2016.

[9] Conservatoire des télécommunications du réseau électrique français, https://www.conservatoire.estelenerg.org/?p=2862 (Accessed: 18/02/2018)

[10] M. Schwartz, ‘CARRIER-WAVE TELEPHONY OVER POWER LINES: EARLY HISTORY’, IEEE Communications Magazine, January 2009, pp. 14-18

References

[11] M. Götz et al., 'Power Line Channel Characteristics and Their Effect on Communication System Design', IEEE Communications Magazine, April 2004, pp, 78-86

[12] A. S. e Beer et al., 'Contactless Power-Line Communications', IEEE International Symposium on Power Line Communications and its Applications ISPLC 2014, pp, 111-115

[13] G. D. Licciardo et al., 'Evaluation of NB-PLC in Railway Environment', 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), pp. 1-5

[14] C. Cano et al., 'State of the art in power line communications: From the applications to the medium', IEEE Journal on Selected Areas in Communications, 2016, vol. 34, no 7, pp. 1935-1952.

[15] S. Galli et al., 'For the grid and through the grid: The role of power line communications in the smart grid', Proceedings of the IEEE, 2011, vol. 99, no 6, pp. 998-1027.

[16] CENELEC EN 50065-1, 'Signaling on Low-Voltage electrical Installations in the Frequency Range 3 kHz – 148.5 kHz', 1992

[17] R. M. de Oliveira et al., 'Medium Access Control Protocols for Power Line Communication: A Survey', IEEE Communications Surveys & Tutorials, 2018

[18] J. Song et al., 'An indoor broadband broadcasting system based on PLC and VLC', IEEE Transactions on Broadcasting, 2015, vol. 61, no 2, pp. 299-308

[19] K. Afridi, 'Wireless Charging of Electric Vehicles', Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2017 Symposium, Washington, DC, The National Academies Press (doi.org/10.17226/24906)

[20] 'Powerline Communication for Street Lighting Automation', application note 5347, Maxim Integrated inc., https://www.maximintegrated.com/en/app-notes/index.mvp/id/5347 (Accessed: 18/02/2019)

References

[21] F. Nouvel et al., 'Experiments of In-Vehicule Power Line Communications', Intech Open, https://www.intechopen.com/books/advances-in-vehicular-networking-technologies/experiments-of-in-vehicle-power-line-communications (Accessed: 18/02/2019)

[22] Navish Lallbeeharry, 'Réseaux d'énergie Embarqués dans les Systèmes de Transport : Communication et Diagnostic Passif par Courant Porteur en Ligne (CPL)', PhD thesis, Lille University, IEMN, 2018

[23] P. Degauque et al., 'Powerline communication for transportation systems: channel characterization and modeling', IEEE VEHICULAR TECHNOLOGY MAGAZINE, 10:2, 2015, pp. 28-37

[24] M. Hoch, 'Comparison of PLC G3 and PRIME', 2011 IEEE International Symposium on Power Line Communications and Its Applications, pp. 165-169

[25] L. Yonge et al., 'An overview of the HomePlug AV2 technology', Journal of Electrical and Computer Engineering, 2013, Hindawi

[26] S. Baig et al., 'High Data Rate Discrete Wavelet Transform-Based PLC-VLC Design for 5G Communication Systems', IEEE Access, 2018, vol. 6, pp. 52490-52499.

[27] Y. Huo et al., 'Cable diagnostics with power line modems for smart grid monitoring', arXiv preprint arXiv:1808.01149, 2018.

[28] F. Marcuzzi et al. 'Artificial intelligence based routing in PLC networks', IEEE International Symposium on Power Line Communications and its Applications (ISPLC), 2018, pp. 1-6.

[29] L. Davolli et al., 'Internet of Things on Power Line Communications: An Experimental Performance Analysis', Smart Grids and Their Communication Systems, Springer, Singapore, 2019. pp. 465-498

[30] H. Gao et al., 'A new digital front end structure for cognitive PLC systems, IEEE International Symposium on Power Line Communications and Its Applications (ISPLC), 2015, pp. 250-255.

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Prof. V. Moeyaert

veronique.moeyaert@umons.ac.be

UMONS Université de Mons

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