A Qing Yang Presentation

@ SmartGridComm 2015

1. wait for start at 13:30, Tuesday, 3 November
2. 52 page, 20 seconds per page

# Powerline-PNC: Boosting Throughput of Powerline Networks with Physical-Layer Network Coding

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1. Good afternoon and welcome to my presentation.
2. The title of my presentation is: Powerline-PNC: Boosting Throughput of Powerline Networks with Physical-Layer Network Coding.
3. My name is ......

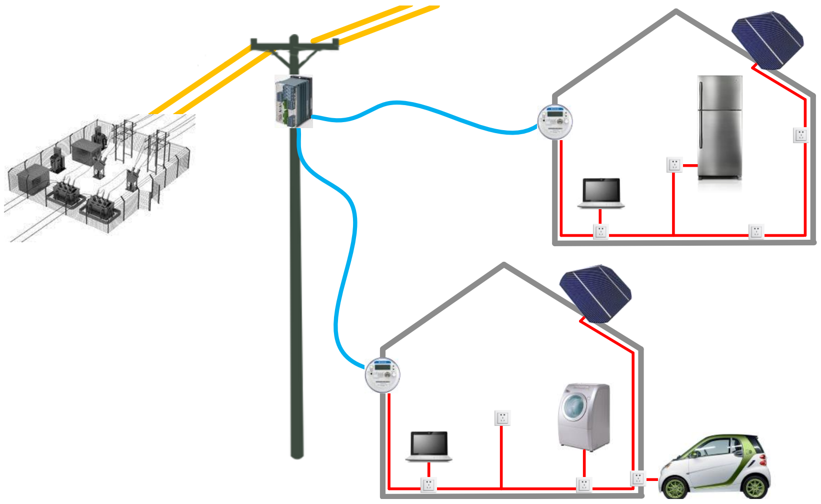
# Outline





1. In the following 20 minutes, I will first introduce the background of this work; then I will present the system design of powerline-PNC and our decoding algorithm; next I will show you our simulation results, and finally conclude this presentation. For the rest of the time, please raise questions if you have any.

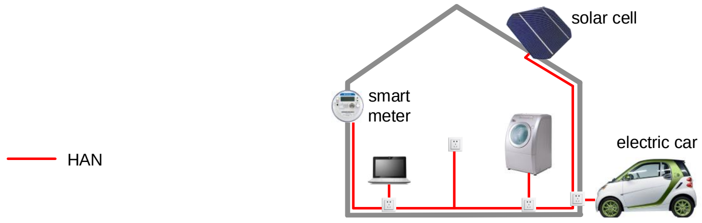
## Powerline communication conveys information via existing powerlines on smart grid





1. Let start with a picture of power grid system. As you see, powerline is ubiquitous in our daily life.
2. Powerline communication conveys information on the existing powerline originally designed for electric power transmission.
3. Powerline communication is becoming a promising technology to enable smart communication infrastructure on smart grid, due to its ubiquity and the potential to deliver high-rate data.

# A typical powerline network consists of HAN, NAN, and WAN

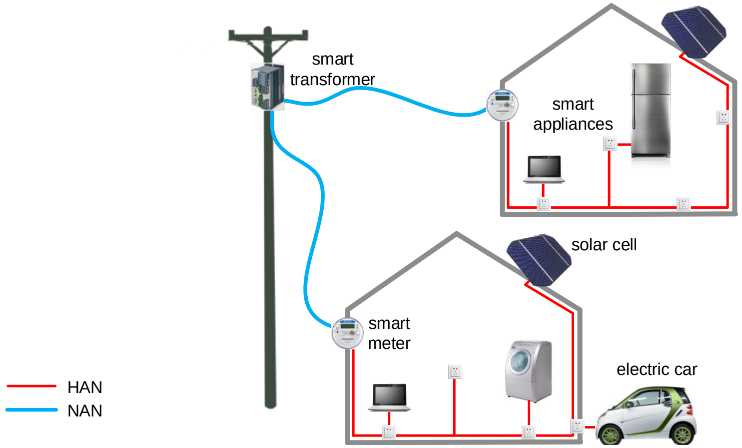



Home area network (HAN)



1. Typically, a powerline network consists of Home area network, Neighborhood area network, and Wide area network.
2. The Home area network connects the smart meter and various in-home smart appliances, e.g., smart electric car.

# A typical powerline network consists of HAN, NAN, and WAN

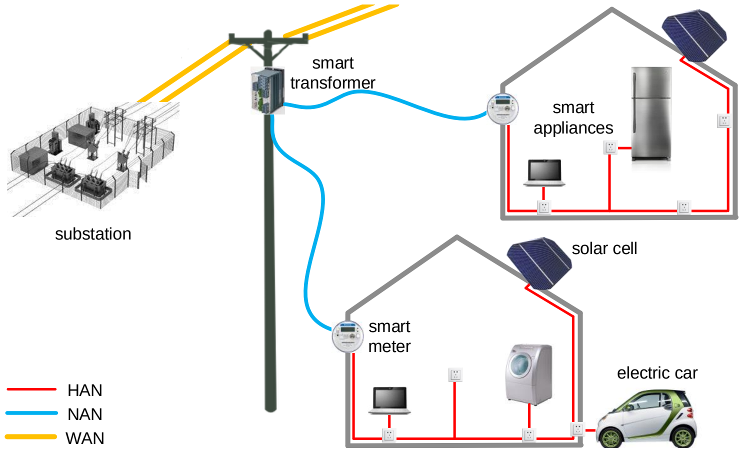



Neighborhood area network (NAN)



1. The Neighborhood area network connects the HANs in the same neighborhood to the smart transformer deployed on the distribution grid.

# A typical powerline network consists of HAN, NAN, and WAN

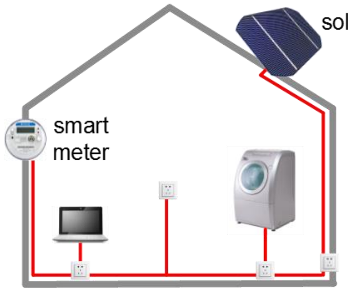



Wide area network (WAN)



1. The Wide area network connects the many NANs to the substation operated by a utility company.

## Home area network follows a star topology including end nodes and a hub node

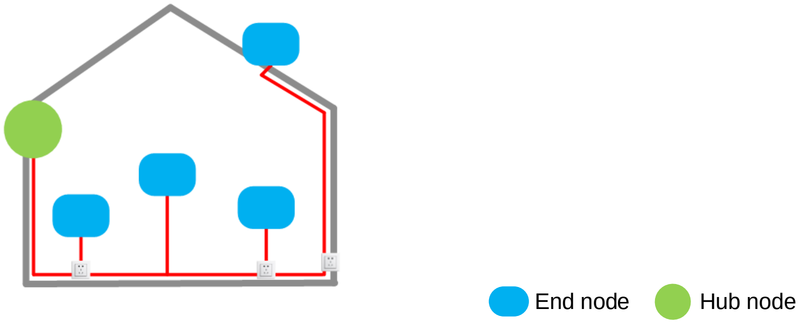



- End node: generates/consumes information
- Hub node: manages the information interchange



1. Now let us look in detail at the home are network, we can regard the smart devices as nodes in a network.

Home area network follows a star topology including end nodes and a hub node

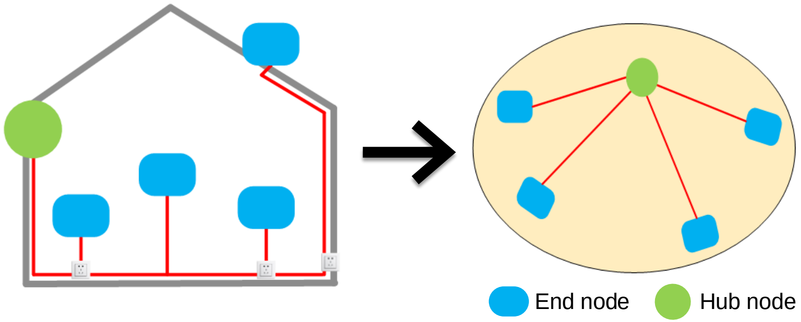



- End node: generates/consumes information
- Hub node: manages the information interchange



1. We divide the nodes in the powerline network into two categories. The hub node is the central node that manages its local network. In this figure, the smart meter is the hub node.
2. The end node is the node that generates and consumes information. In this figure, the end nodes are the smart appliances.

## Home area network follows a star topology including end nodes and a hub node

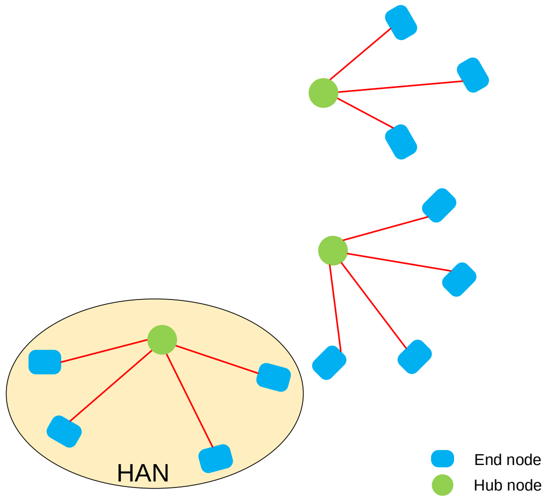



- End node: generates/consumes information
- Hub node: manages the information interchange



1. As a result, the home area network on the left is abstracted to the star-topology on the right.

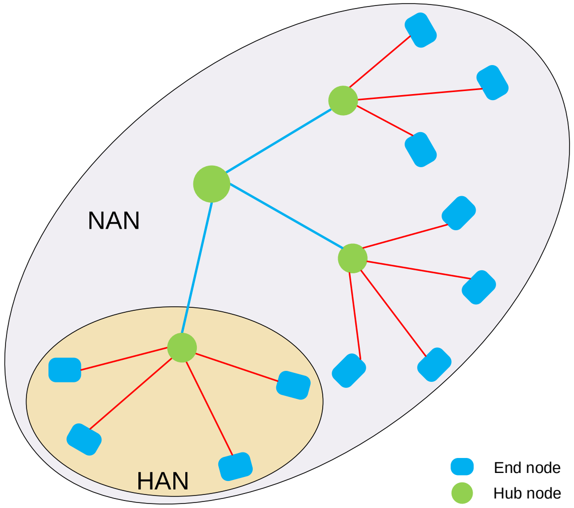
## Powerline network is a “network of networks”






1. As we know, there are a lot of such home area networks in a powerline system.

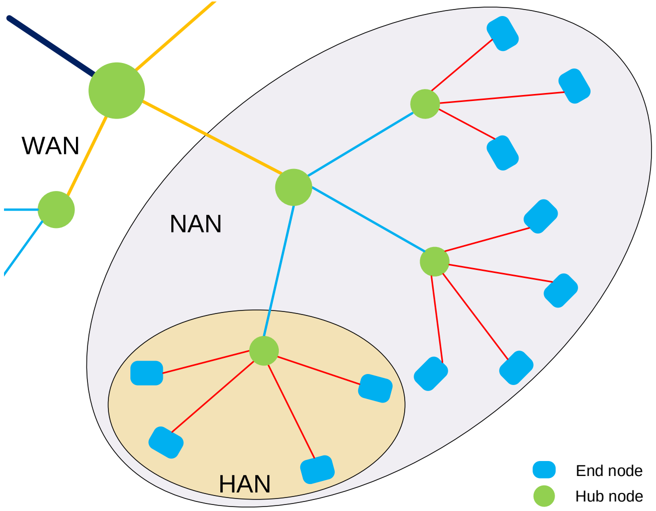
## Powerline network is a “network of networks”






1. From a bird’s eye view, the overall powerline network is a “network of networks”.

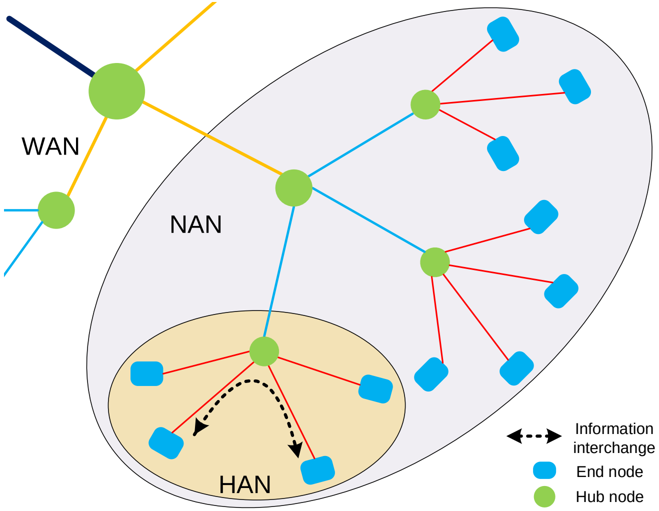
## Powerline network is a “network of networks”






1. This network has a hierarchical star-network topology. With the large number of end nodes on the smart grid, the scale of powerline network can be very large.

# Bi-directional information interchange is common on smart grid

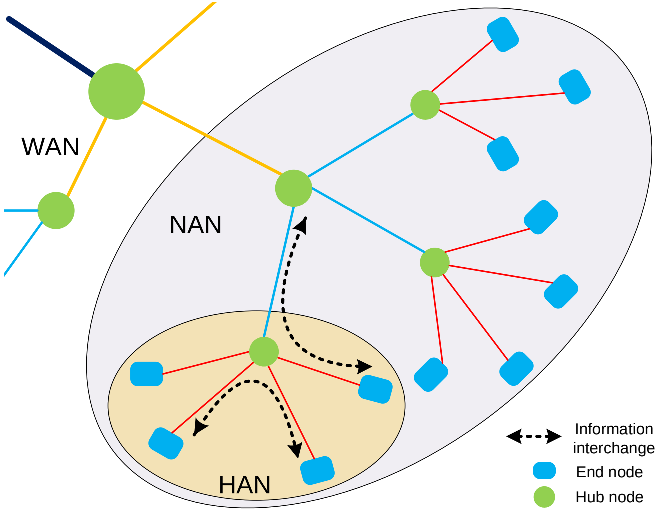



Between end nodes



1. On smart grid, bi-directional information exchange is a common communication pattern.
2. This bi-directional information exchange can happen between end nodes... (next page)

# Bi-directional information interchange is common on smart grid

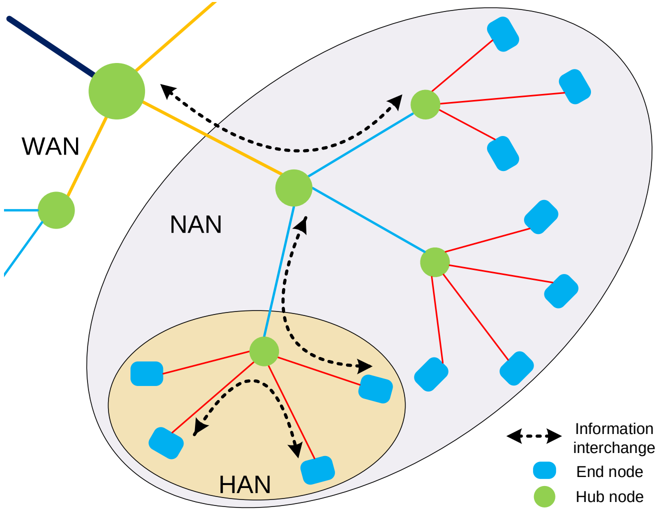



Between end node and hub node



1. ...or Between a end node and a hub node...(next page)

# Bi-directional information interchange is common on smart grid

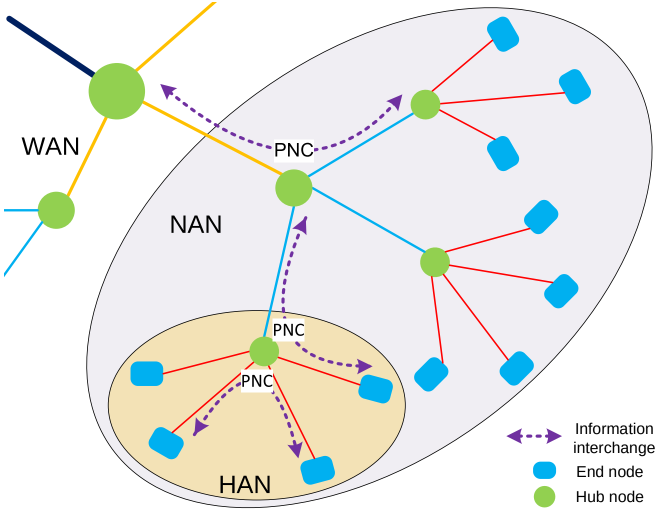



Between hub nodes



1. ...or Between hub nodes.
2. So, a big challenge for the large-scale powerline network is, how to achieve high-throughput low-latency information interchange.

# Powerline-PNC: boost the network throughput using physical-layer network coding






1. To address this challenge, we designed Powerline Physical-layer Network Coding, a network architecture that adopts physical-layer network coding to boost the throughput of powerline networks.

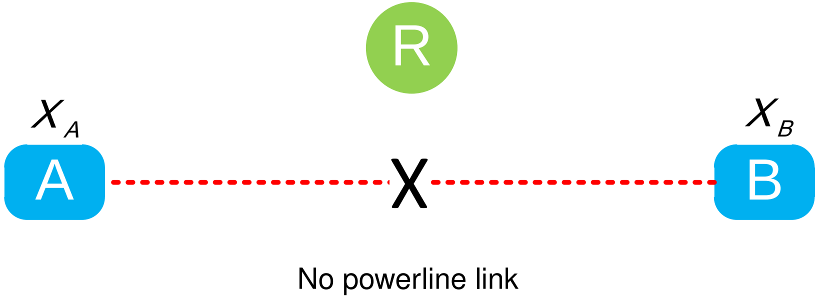
## The channel model of bi-directional information exchange


End nodes exchange a pair of packets



1. Now, let's consider the channel model of bi-directional information exchange. Here we have two end nodes, node A and node B. A hub node, node R.
2. Node A and node B want to exchange a pair of packets, $X_A$ and $X_B$.

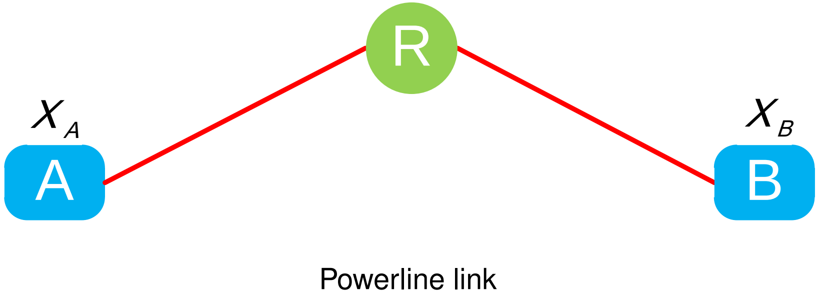
# The channel model of bi-directional information exchange






1. However, node A and node B cannot communicate directly because of the distance.

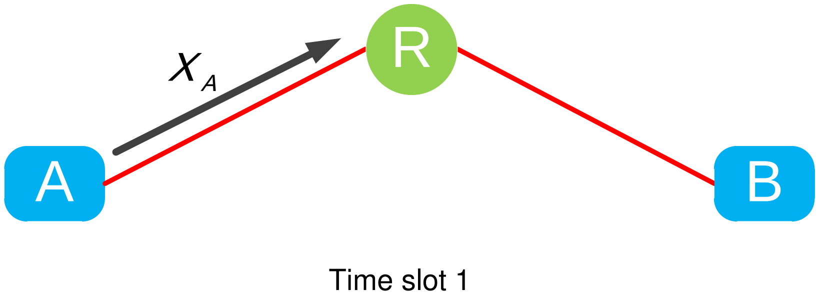
# The channel model of bi-directional information exchange






1. And node A and node B both connects to the hub node R via powerline. So they exchange their packets with the help of R.

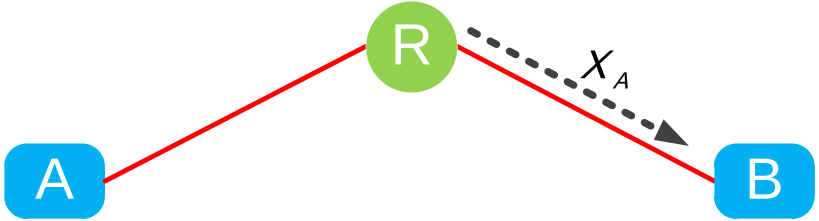
## Conventional bi-directional information exchange takes four time slots





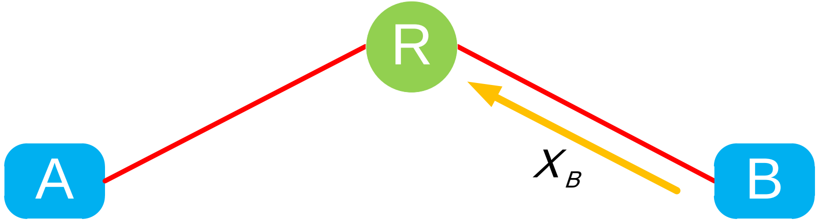

1. Now, let's first look at the conventional packet exchange method, it takes four time slots to exchange a pair of packets.

# Conventional bi-directional information exchange takes four time slots



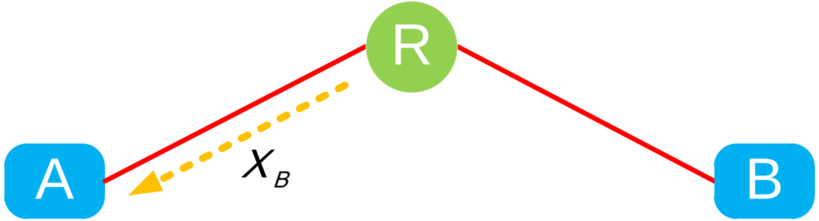

Time slot 2

# Conventional bi-directional information exchange takes four time slots



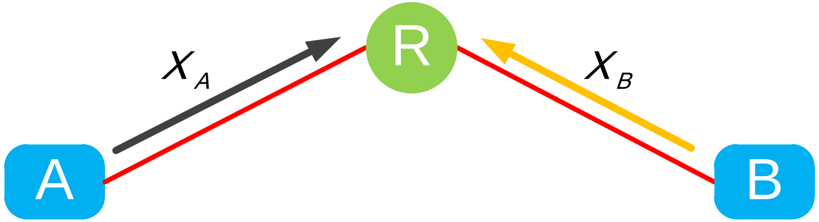

Time slot 3

# Conventional bi-directional information exchange takes four time slots




Time slot 4

## Physical-layer network coding (PNC) takes only two time slots

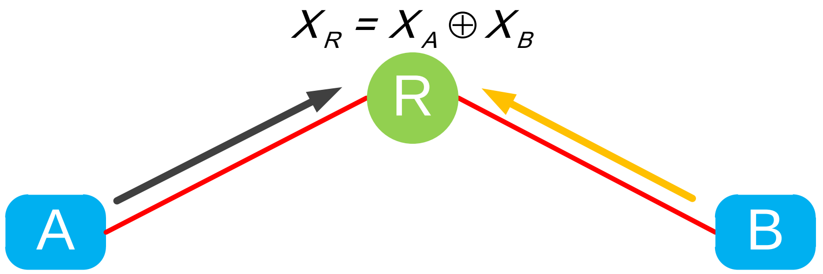



Time slot 1: multiple access



1. In contrast, with physical-layer network coding, we only need two time slots. In the first time slot, node A and B transmit their packets simultaneously to the hub node on the same spectrum.

## Physical-layer network coding (PNC) takes only two time slots

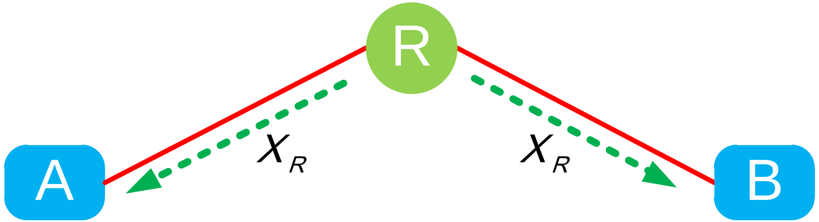



PNC mapping



1. So the hub node receives a overlapped signal of $X_A$ and $X_B$. The hub node decodes this overlapped signal to the XOR of $X_A$ and $X_B$.

## Physical-layer network coding (PNC) takes only two time slots

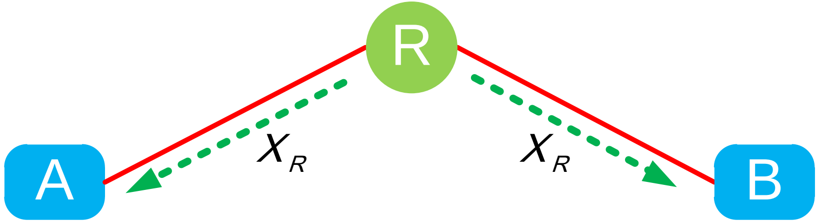



Time slot 2: broadcast



1. In the second time slot, the hub node broadcast the XOR packet $X_R$ to node A and node B.

## Physical-layer network coding (PNC) takes only two time slots




Node A: $X_A \oplus X_R = X_A \oplus (X_A \oplus X_B) = X_B$

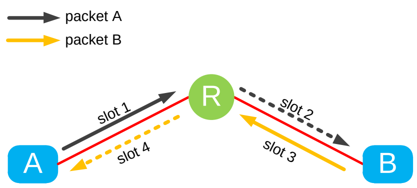
Node B: $X_B \oplus X_R = X_B \oplus (X_A \oplus X_B) = X_A$



1. Then, node A and B can retrieve other's packet by XOR $X_R$ with its own packet.

# PNC doubles the throughput of conventional bi-directional information exchange

Conventional scheme



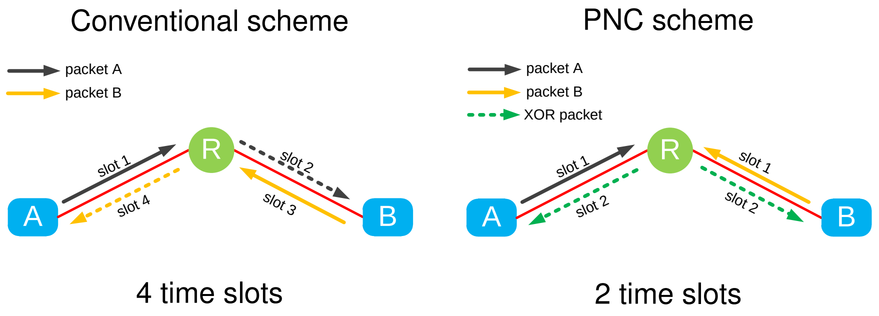

4 time slots

Throughput 100% up!



1. In this example, conventional powerline takes four time slots.

# PNC doubles the throughput of conventional bi-directional information exchange

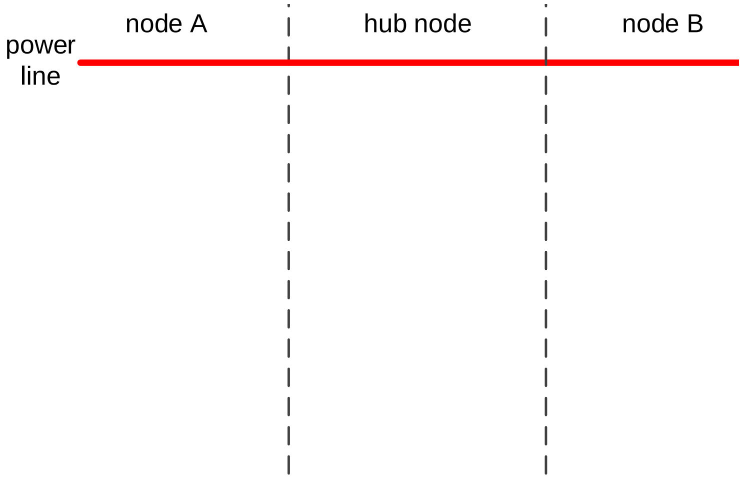



Throughput **100%** up!



1. And PNC only needs two time slots.
2. Compared with conventional scheme, physical-layer network coding increase the throughput by 100 percent.

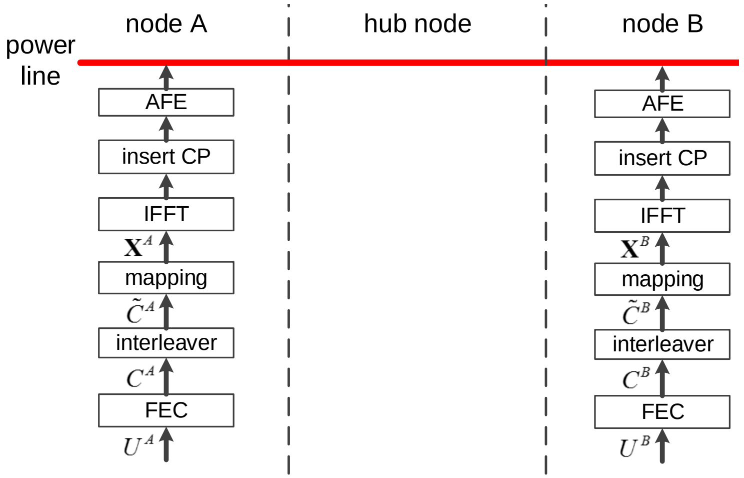
## Physical-layer design of Powerline-PNC





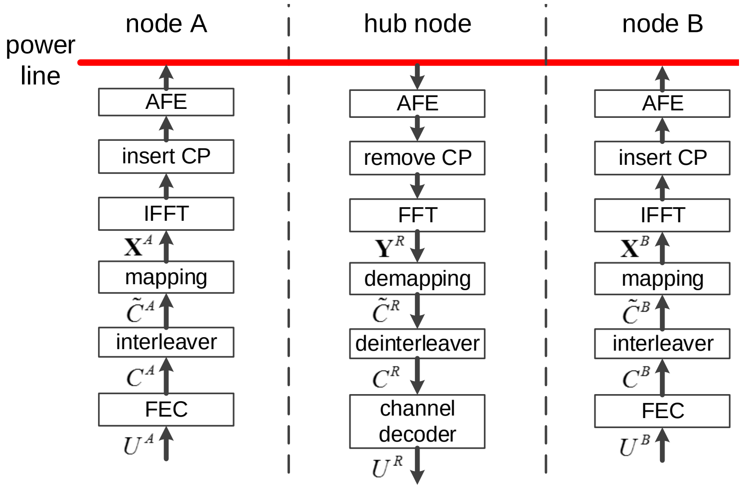

1. Okay, now let's move on to the system design. In this slide, we present the design of the physical-layer for the powerline-PNC. Since powerline channel is harsh.
   Our goal is to guarantee reliable communication on powerline.

# Physical-layer design of Powerline-PNC




1. In the end nodes, we assume forward error control and interleaving. The channel code is concatenated Reed-Solomon convolutional code. We assume OFDM modulation.

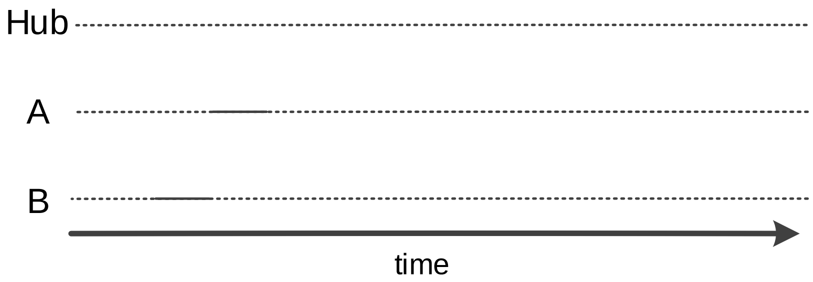
## Physical-layer design of Powerline-PNC






1. In the hub node, we first do OFDM demodulation on the received signal. Then we perform PNC demapping and deinterleaveing. At last, the channel decoder decodes the XOR packet.

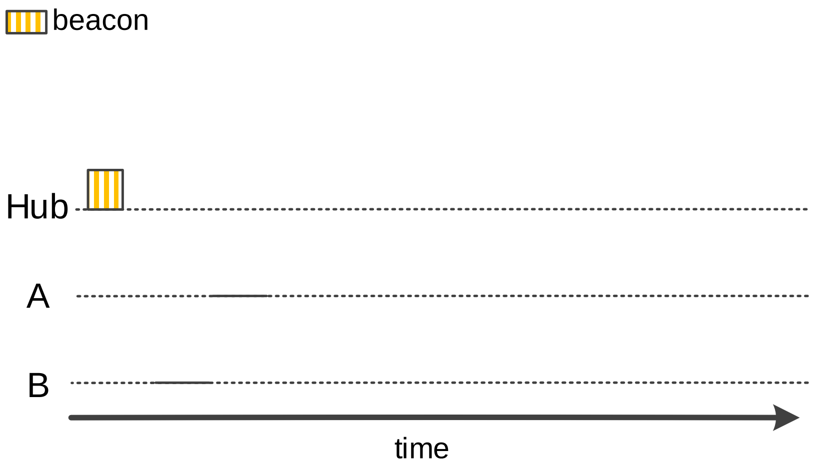
## The medium access control precedure of Powerline-PNC






1. This slide shows the medium access control precedure of Powerline-PNC. We designed a beacon-triggered transmission scheme to ensure the simultaneous transmission of the end nodes.
2. Let's consider the timeline of the time-slotted system.

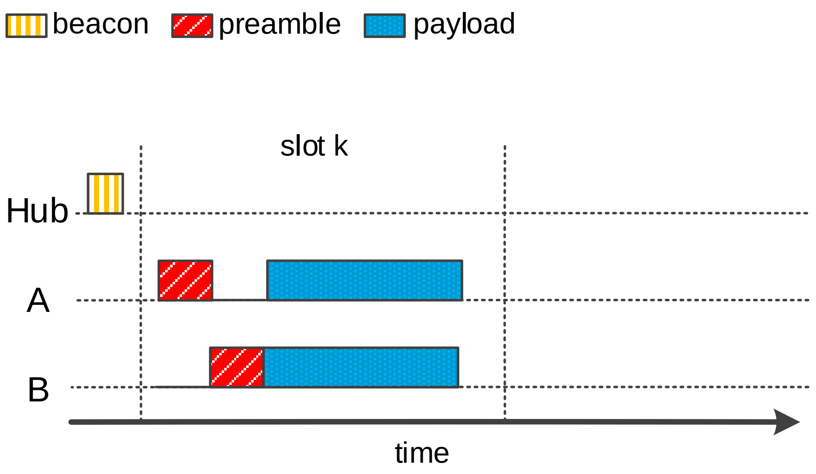
## The medium access control precedure of Powerline-PNC






1. First, the hub node broadcasts a short beacon packet to trigger the end nodes to transmit.

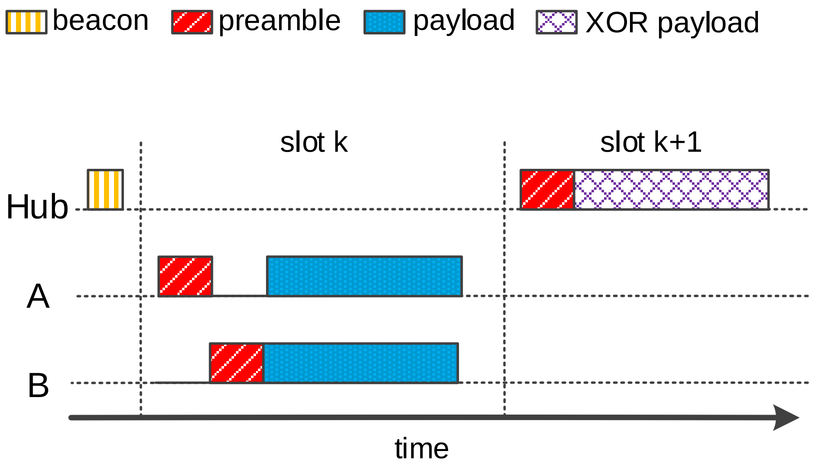
## The medium access control precedure of Powerline-PNC






1. When detecting the beacon signal, node A and B transmit their packet to the hub node.
2. The transmitted packet consists of orthogonal preamble for channel estimation, and payload for data. When the hub node receives this overlapped packet, it decode the packet using PNC decoding algorithm. We will discuss the decoding algorithm later.

## The medium access control precedure of Powerline-PNC






1. In the following time slot, the hub node broadcasts the XOR packet to the end nodes.

## End nodes encode packets using concatenated Reed-Solomon/convolutional code

Source packets

$$U^i = \left(u_1^i, u_2^i, \cdots, u_L^i\right), \ i \in \{A, B\}, \qquad (1)$$

Channel-coded packets

$$C^i = \left(c_1^i, c_2^i, \cdots, c_M^i\right), \ i \in \{A, B\} \qquad (2)$$



1. Now, let's move on to the decoding algorithm of physical-layer network coding.
   We let $U^i$ denote the source packet from node i. Let $C^i$ denote the channel-coded packet from node i.

# Then, the packet is interleaved and OFDM modulated

Interleaving at the end nodes

$$\Pi\left(C^i\right) = \tilde{C}^i \quad (3)$$

The frequency-domain signal is

$$\mathbf{X}^i = \begin{bmatrix} X^i_{1,1} & X^i_{1,2} & \cdots & X^i_{1,N} \\ X^i_{2,1} & \ddots & & \vdots \\ \vdots & & & \\ X^i_{K,1} & \cdots & & X^i_{K,N} \end{bmatrix}, \ i \in \{A, B\} \quad (4)$$

where $X^i_{k,n}$ denotes the $n$-th sample on the $k$-th subcarrier of $\mathbf{X}^i$



1. Then, the packet is interleaved $C^i$ to produce $\tilde{C}^i$, and OFDM modulated to produce the transmitted signal.

## Received complex baseband signal at the hub node

$$Y^R_{k,n} = h^A_k X^A_{k,n} + h^B_k X^B_{k,n} + w^R_{k,n} \quad (5)$$

where

- $Y^R_{k,n}$ is the frequency-domain signal
- $h^A_k$ and $h^B_k$ are the channel coefficients on the $k$-th subcarrier



1. Upon receiving the overlapped signal. The hub node first OFDM demodulates the overlapped signal.
2. And use this signal to compute the XOR packet.

# Maximum likelihood XOR channel decoding algorithm

The likelihood of the XOR bit $\tilde{C}^R_{k,n}$

$$\Pr\left(Y^R_{k,n}\middle|\tilde{C}^R_{k,n}\right) = \sum_{X^A_{k,n}, X^B_{k,n} : \tilde{C}^A_{k,n} \oplus \tilde{C}^B_{k,n} = \tilde{C}^R_{k,n}} \Pr\left(Y^R_{k,n}\middle|X^A_{k,n}, X^B_{k,n}\right) \quad (6)$$

where

$$\Pr\left(Y^R_{k,n}\middle|X^A_{k,n}, X^B_{k,n}\right) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{\left|Y^R_{k,n} - h^A_k X^A_{k,n} - h^B_k X^B_{k,n}\right|^2}{2\sigma^2}\right\} \quad (7)$$



1. The likelihood of the XOR bit is calculated using equation (6); from this equation, we can obtain the maximum likelihood estimation of the XOR packet.

## Deinterleaving and channel decoding

The hub node first deinterleaves the XOR codeword

$$\Pi^{-1}\left(\tilde{C}^A \oplus \tilde{C}^B\right) = \Pi^{-1}\left(\tilde{C}^A\right) \oplus \Pi^{-1}\left(\tilde{C}^B\right) = C^A \oplus C^B \qquad (8)$$

Then channel-decode the deinterleaved XOR packet

$$\mathcal{C}^{-1}\left(C^A \oplus C^B\right) = \mathcal{C}^{-1}\left(C^A\right) \oplus \mathcal{C}^{-1}\left(C^B\right) = U^A \oplus U^B \qquad (9)$$



1. Then, the hub node deinterleaves and channel decodes the XOR packet. Because the deinterleave and decoding operation are linear, so we can obtain the XOR source packet in equation (9).
2. And then, the hub node broadcast the XOR packet to both the end nodes.

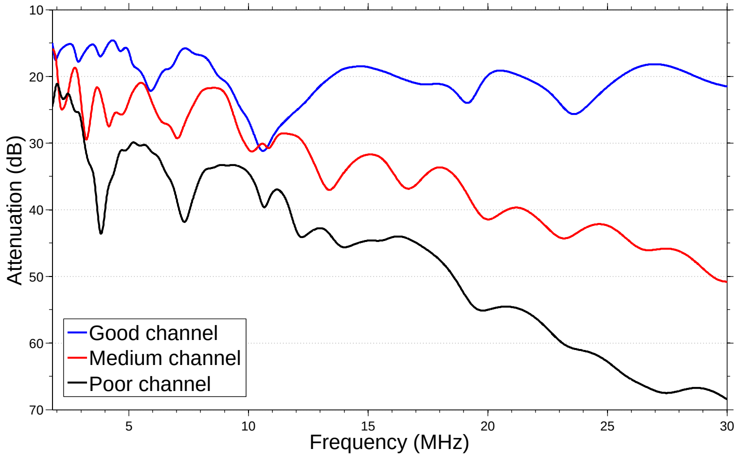
## Simulation parameters

- 1.8–30MHz frequency band
- OFDM with 917 subcarriers
- Concatenated (255, 239) Reed-Solomon and (171, 133) convolutional code



1. Okay, in the following slides, we evaluated the powerline-PNC using extensive simulations.
   We assume OFDM modulation on 1.8–30MHz frequency band; and Concatenated Reed-Solomon and convolutional code.

# Evaluate the Powerline-PNC under broadband powerline channels modeled from practical powerline

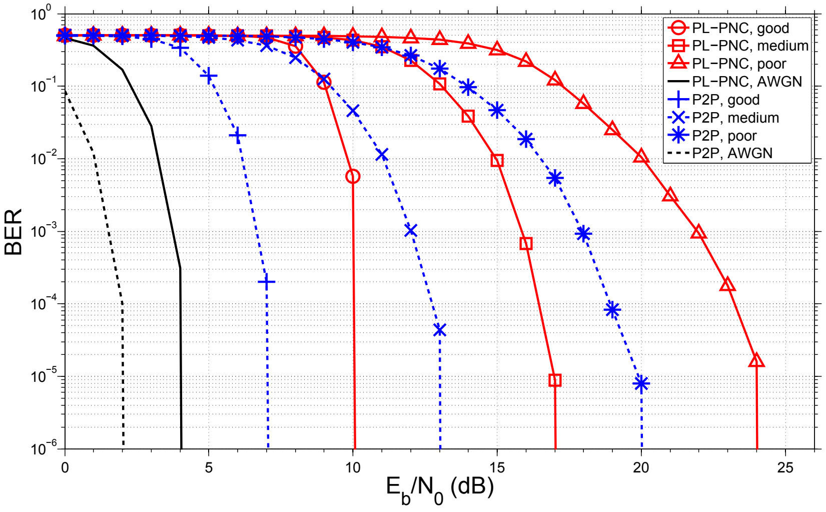



F. Canete, J. Cortes, L. Diez, and J. Entrambasaguas, "A channel model proposal for indoor power line communications," IEEE Commun. Mag., vol. 49, no. 12, pp. 166–174, 2011.



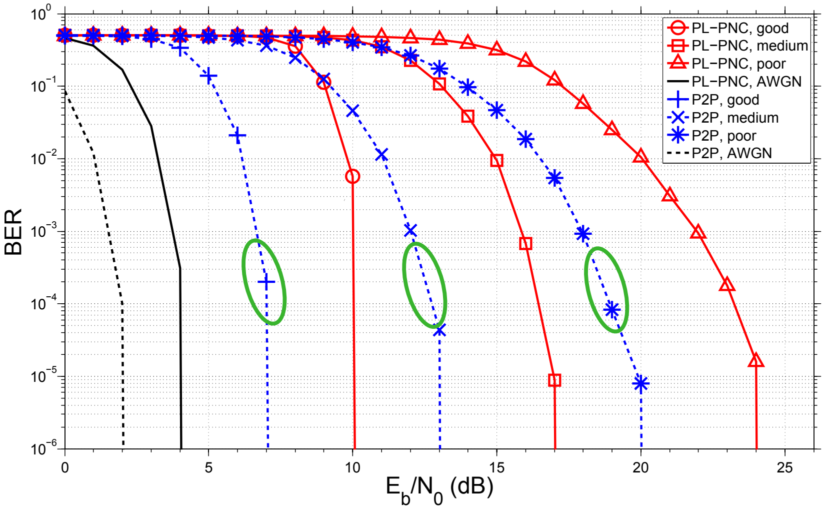
1. The powerline channels are modeled from practical powerline, using the method proposed in this paper. We consider three channel conditions: good, medium, and poor, as shown in the figure.

## Bit error rate (BER) performance



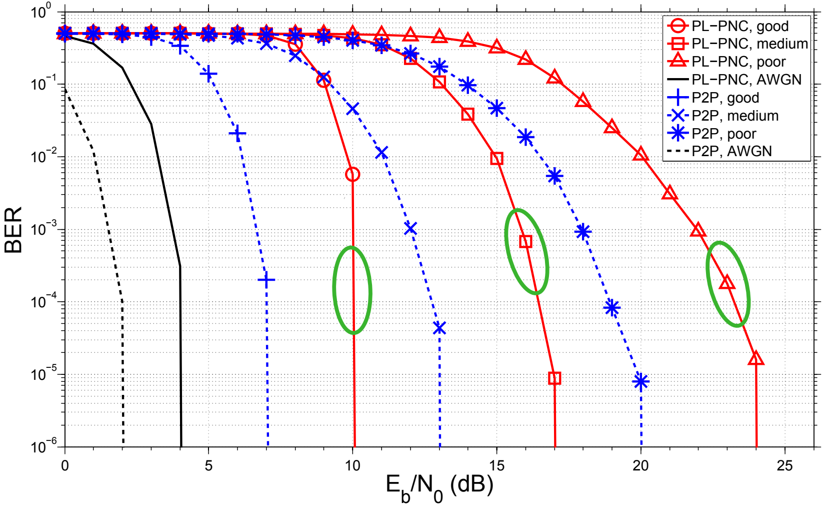

1. This figure shows the BER performance of powerline-PNC and conventional method, for bi-directional information exchange.

# Bit error rate (BER) performance



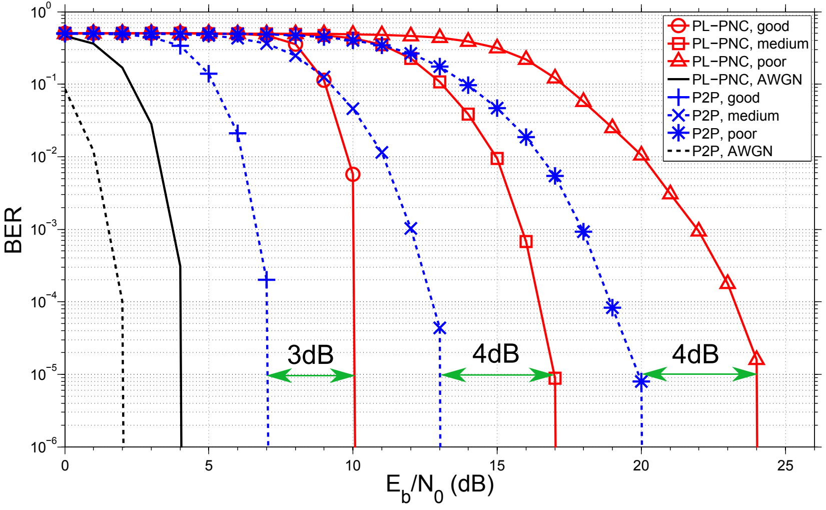

1. The blue dashed line is the conventional method.

# Bit error rate (BER) performance



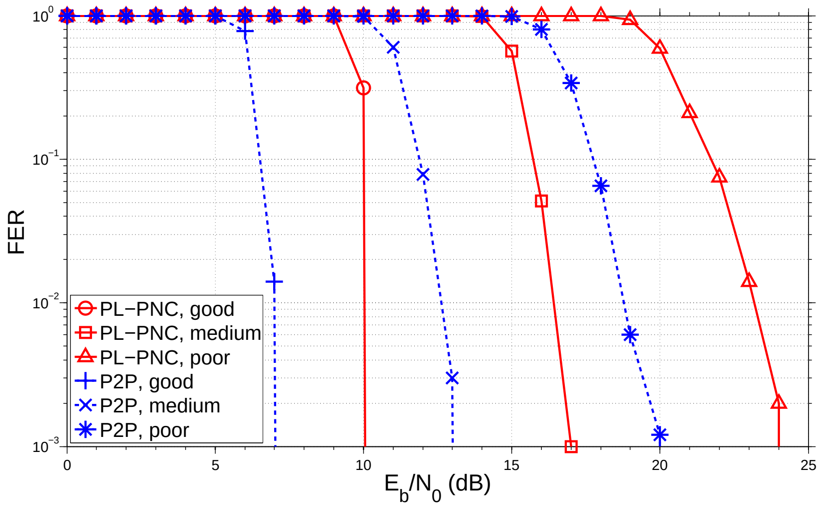

1. The red solid line is the BER of powerline-PNC.

## Bit error rate (BER) performance



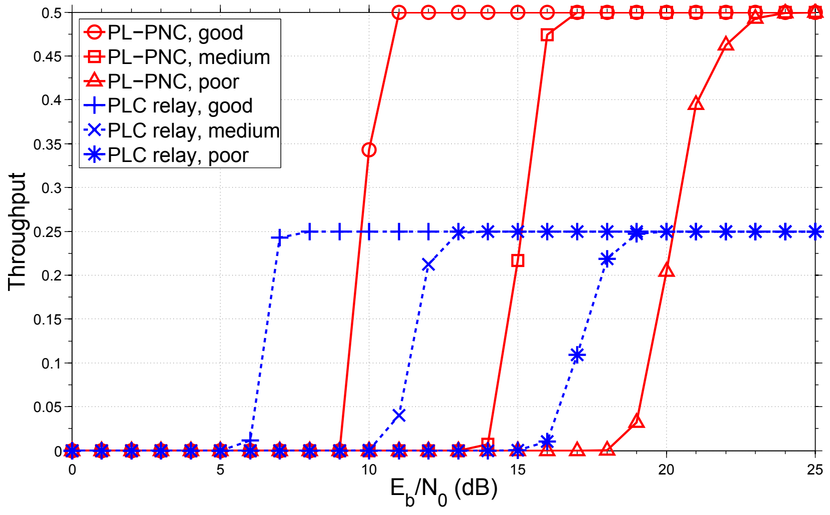

1. So in terms of BER, powerline-PNC is worse than conventional PLC.

# Frame error rate (FER) performance



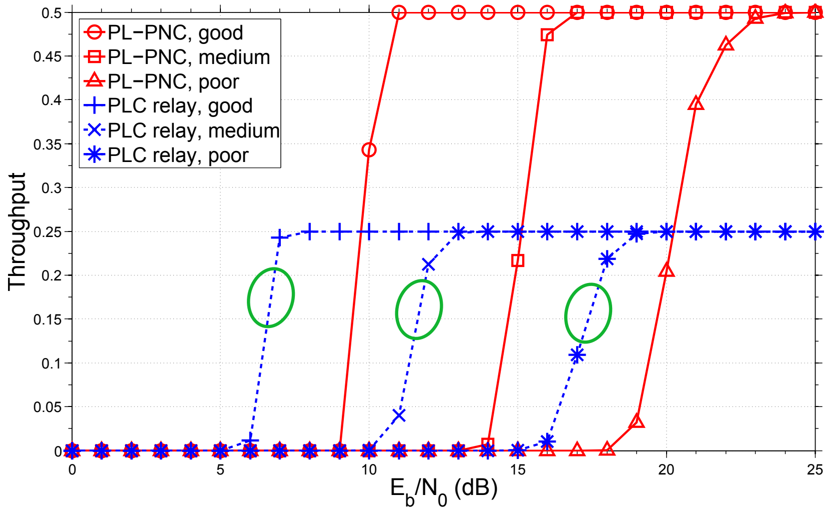

1. This figure shows the frame error rate of powerline-PNC and conventional method, under different channel conditions.
   From the FER, we can compute the throughput, which is shown in next slide.

## Throughput of bi-directional information exchange Powerline-PNC vs conventional PLC



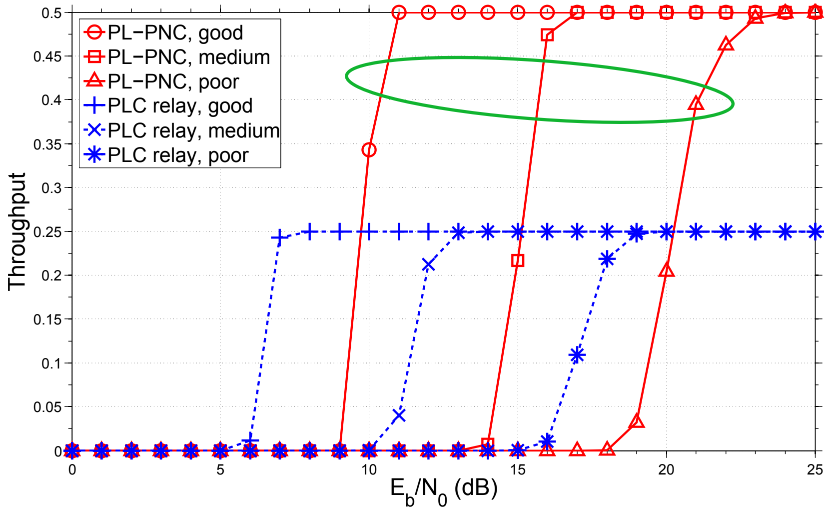

1. This figure shows the throughput of Powerline-PNC and conventional method, for bi-directional information exchange.

# Throughput of bi-directional information exchange Powerline-PNC vs conventional PLC



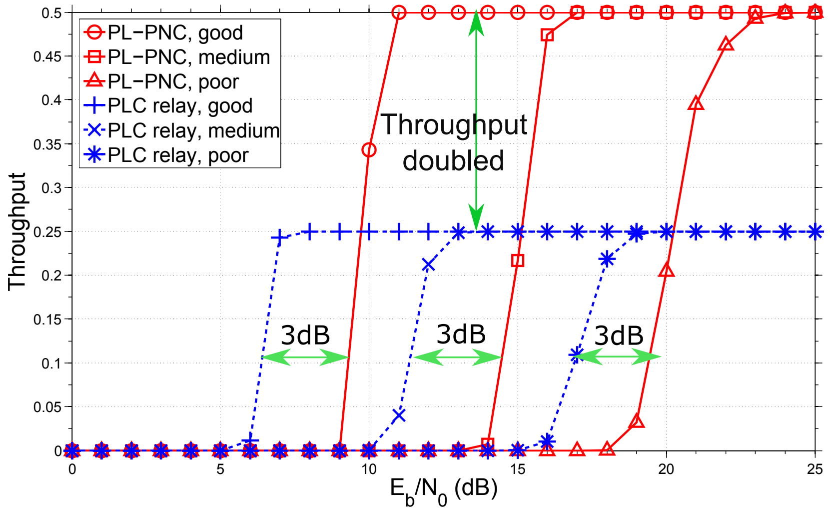

1. The blue dashed line is for the conventional PLC.

## Throughput of bi-directional information exchange Powerline-PNC vs conventional PLC




1. The red solid line is for Powerline-PNC.

## Throughput of bi-directional information exchange Powerline-PNC vs conventional PLC




1. Compared with conventional PLC, Powerline-PNC doubles the throughput, at a cost of 3dB.

## Powerline-PNC is the first work employing PNC to powerline communication networks

Our main contributions are:

- Design both the MAC and PHY layers of Powerline-PNC
- Powerline-PNC improves the throughput by 100% at the SNR cost of 3 dB
- Show that Powerline-PNC is viable through extensive simulations



1. Well, that brings us to the end of my presentation. Let me summarize the main points.
2. We design both the MAC and PHY layers of the proposed Powerline-PNC system to be compatible with the existing IEEE 1901 standard.

## Powerline-PNC is the first work employing PNC to powerline communication networks

Our main contributions are:

- Design both the MAC and PHY layers of Powerline-PNC
- Powerline-PNC improves the throughput by 100% at the SNR cost of 3 dB
- Show that Powerline-PNC is viable through extensive simulations



1. We show that Powerline-PNC improves the throughput of traditional powerline networks by 100 percent at the SNR cost of 3dB.

## Powerline-PNC is the first work employing PNC to powerline communication networks

Our main contributions are:

- Design both the MAC and PHY layers of Powerline-PNC
- Powerline-PNC improves the throughput by 100% at the SNR cost of 3 dB
- Show that Powerline-PNC is viable through extensive simulations



1. We show that Powerline-PNC is viable through extensive simulations adopting practical powerline channel models.

# Q&A Session

Your questions are welcomed

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1. Thanks for your attention.
2. If you have any question, please feel free to contact the author.