Specific Systems:

Broadband Powerline Communications Networks (PLCs) #16

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Outline

• What is a PLC?
• Topology
• Channel characteristics
• Noise characteristics
• A MAC protocol for PLC networks
  - Assumptions
  - Operation
• MAC protocol is an example of:
  - Earliest deadline first scheduling
  - Scheduling algorithm that accounts for retransmissions
What is a Broadband PLC Network

- Powerlines have been used for:
  - Low speed data transport for many years
    - Control
    - Telemetry
  - In home power wiring have been used for networking
  - Broadband PLC is an alternative for internet access-last mile

Broadband PLC topology

Modified from: Design and performance evaluation of an hybrid reservation polling MAC protocol for power-line communications

From: Distributed MAC protocols and priority oriented scheduling
for a PLC access network Sundaresan, S. Anand, S. Srikanth, y and C. N.
**Broadband PLC System Architecture**

- OM = outdoor master
- OR = outdoor repeater
- OAP = outdoor access point
- IA = Indoor adaptor
- IC = Indoor Controller

**PLC Channel**

- Time varying
- Frequency dependent
- EMC issues with amateur radio operators
- CENELEC (European Committee for Electrotechnical Standardization)
  - Europe
  - 3-148.5 kHz
  - 5 mW
  - 144 kb/s
- Broadband PLC: 1-30 Mhz
**PLC noise environment**

- **Colored background noise**
  - Source: Sum of low power noise sources
  - Timescale: minutes to hours
- **Narrowband noise**
  - Source: broadcast stations
  - Timescale: varies with time of day
- **Periodic impulsive noise asynchronous to the main frequency**
  - Source: Switching power supplies
  - Timescale: ms (repetition rate 50-200Hz)
- **Periodic impulsive noise synchronous to the main frequency**
  - Source: appliances
  - Timescale: ms (repetition rate 50-100Hz or 60Hz and 120Hz), duration 10-100us
- **Asynchronous impulsive noise**
  - Source: Switching transients in the power grid
  - Timescale: duration us-ms and level 50dB above background noise level
  - Major source of errors
Estimation of Channel Capacity for Broadband PLC Networks

- Based on last mile capacity analysis in: “Powerline Communications”, Klaus Dostert, Prentice Hall 2001
  - Channel characteristics
  - Noise characteristics

<table>
<thead>
<tr>
<th>Link Length</th>
<th>Best Case</th>
<th>Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-300m</td>
<td>250 Mb/s</td>
<td>14 Mb/s</td>
</tr>
<tr>
<td>Theoretical</td>
<td>100 Mb/s</td>
<td>5 Mb/s</td>
</tr>
</tbody>
</table>

A MAC protocol for Broadband PLC Networks


- Assumptions
  - Fast ARQ is better than FEC in impulsive noise environments like broadband PLC
    - FEC has a constant bandwidth penalty
    - Fast ARQ is only invoked when errors, here induced via impulsive noise.
  - Half duplex channel: same resources used for up and down stream communications
  - Time division
    - Frames
    - Slots
    - Minislots
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Types of Slots:
- Downlink
- Uplink
- Reservation

F=Framing
C_i=Command
-AU ID
-Acks


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- **DLW**
  - Link layer at AU send ACK on a slot by slot basis \(\rightarrow\) fast retransmission

- **UPL**
  - Supports one fixed length packet
  - AU's request slots
  - BS grants slots
  - Acks for UPL from AU_i are piggybacked in the control in next DLW even if slot not destine for AU_i

- **RSV**
  - AU has packet to send \(\rightarrow\) contending state
  - Reservation slots are subdivided into minislots
  - A random access protocol like ALOHA is used for contention
  - When BS receives a minislot for AU_i, a grant for AU_i is placed in a polling list
  - The command in the next DLW contains a reservation ack
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- A connection set-up is used to identify all AU’s that can access the channel
  - AU’s are given a connection ID
  - AU’s provide traffic/QoS parameters
    - Maximum tolerable delay (MD)
    - Data Rate expressed as interarrival time (IT), maybe dynamically updated for VBR traffic
  - For each AU the BS also tracks
    - The remaining lifetime head-of-line packet = MD - W; W is waiting time for HOL packet
    - Number of retransmission attempts

- AU states
  - Idle
  - Active
  - Contending

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- Active → AU is granted slots according to scheduling rules
- Transition from Active → Idle: AU notifies BS to stop sending grants
- Transition from Idle → Active: AU enters contending state
- Controlling the frequency of RSV slots
  - Too frequent → uses capacity
  - Not frequent enough → high delay
  - Proposed process
    - Issue RSV slot every T sec
    - If one collision of a minislot in RSV then send consecutive RSV slots subject to QoS constraint
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• The BS is designed to be an earliest deadline first scheduler
• Let $MD_{\text{max}} = \text{Max} \ MD \ of \ all \ AU's$
• Set up a polling register that controls the order of polling the AU's
• AU placed at position $k$ in the polling register implies that the relevant packet must be transmitted on the channel in at most $k$ slots, otherwise it expires
• Upon reservation the AU ID is placed a position $MD-W$ or below.

<table>
<thead>
<tr>
<th>$MD_{\text{max}} - 1$</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>$k$</th>
<th>ID for target AU transmission time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

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• If no retransmissions then the scheduler issues grants for the AU in the lowest position in the polling register
• The AU in the bottom position of the polling register is always transmitted, it is that packets last opportunity.
• If retransmissions then the scheduler issues grants for the AU in the lowest position in the polling register and a retransmission counter
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• At the end of a transmission the BS learns
  - Transmission successful
    • If the AU is active the next grant is scheduled interarrival time (IT) slots later
  - Transmission successful
    • If the AU transitions from active to idle the AU is removed from polling register
  - Transmission unsuccessful
    • Leave in same position in polling register and increment the retransmission counter
    • Note that MAC/scheduled deals with retransmissions

• The polling register is shifted down each time slot.
• Note if packet in bottom of the polling register is corrupted then it is lost, that is a retransmission will exceed MD for that AU.
• Use of retransmission counter
  - the transmission grant is assigned to the station in the lowest register position, among the ones with lowest retransmission counter value
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• Example:
  - 3 AUs
  - Assume \( W_A = W_B = W_C = 0 \)
  - Minislot for A arrives first, MD = 5 so place in 5th position in polling register
  - Minislot for B arrives second, MD = 4 so place in 4th position in polling register
  - Minislot for C arrives last, MD = 4, 4th position in polling register is full, so place in 3rd position in polling register

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>MD = 5</td>
<td>MD = 4</td>
<td>MD = 4</td>
</tr>
<tr>
<td>IT</td>
<td>IT = 3</td>
<td>IT = 3</td>
<td>IT = 4</td>
</tr>
</tbody>
</table>

RSV Slot

• AU_C is lowest in polling register so it is transmitted
• Assume this packet is corrupted
• Left in same position before shift down
• Increment retransmission counter shown by X
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- B granted next
  - Lowest in polling register with lowest retransmission count
- Assume B successful

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- Using $IT_g = 3$ MD $= 4$: a new reservation for B in placed in the 4th location
- Note A is next to be granted and assume it is corrupted
- Increment its retransmission counter
- So stays in polling register and after shift down is in the 2nd location
- New reservation for A is not placed in the polling register until the previous one is cleared out
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- C is given a grant next because it is in the bottom position of the polling register.
- Assume this is successful.
- So a new reservation for C is placed in the polling register because it has an MD = 4.

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- In time slot 5 a grant is given to AU B.
- Assume this is transmission is successful.
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- AU A is given a grant for slot 6
- Assume this is successful
- Now new reservation for AU A can be placed on the polling register; should go in position 2, but after shift C is there so it goes in position 1
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• Multiple classes of service
  - Allow more than one AU per position in the polling register
    • Low priority AU granted after all high priority AU
    • View as multiple polling registers; when the high priority polling register is empty the low priority polling register is used to make grants
  - Rearrange the polling register
    • High priority AU's are substituted for low priority AU's in the polling register

Performance Evaluation*

• Focus on Packet voice with on/off model
  • Ave on time = 1 sec
  • Ave off time = 1.3 sec
  • Durations ~ exponentially
  • Slot time 576 bits
    • payload
    • Command
    • Packet header
    • Guard time
  • Packet interarrival time = 16 ms
• Rates 720 Kb/s, 1.44 Mb/s and 2.88 Mb/s
• Noise
  • Gilbert model
  • Good/Bad states
  • Bad state models impulse noise
  • IMT mean time between noise bursts

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**Conclusions**

- **MAC protocol is an example of:**
  - Earliest deadline first scheduling
  - Scheduling algorithm that accounts for retransmissions
- **PLC access networks operate in a harsh environment**
- **Available capacity is not very high**
- **Requires MAC protocols to overcome impulsive noise**
- **Standards still evolving**
References
