DIANA: A Machine Learning Mechanism for Adjusting the TDD Uplink-Downlink Configuration in XG-PON-LTE Systems

Paper Review
Group Meeting Presentation

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Motivation

- Optical technology offers huge bandwidth and, in case of PONs, a cost-effective solution for creating a lightpath in the access domain.

- On the other hand, 4G technologies, such as LTE and LTE Advanced (LTE-A), exhibit high-speed wireless communication for mobile phones and advanced user terminals (laptops, tablets and smart phones).

- This paper:
  - Proposes A hybrid (optical/wireless) architecture with the convergence of the two technologies;
  - Uses SDN capable of collecting and providing traffic-status information;
  - Adjusts LTE Time Division Duplex (TDD) uplink-downlink configuration based on the information provided by SDN controller using a proposed learning scheme called DIANA;
  - Reduces latency and jitter.
Hybrid Optical/Wireless Architecture

- XG-PON systems to support 10 Gbps in at least one direction.
- LTE operates in TDD mode.
- Two wavelength are used, one for the upstream transmission at 1270 nm and the other for the downstream transmission at 1577 nm.
- XG-PON downstream/upstream transmission period is 125usec.
SDN Controller

- SDN controller (not shown in figure) manages ONU Management and Control Interface (OMCI) to capture traffic data information in both directions.

- The knowledge obtained by SDN controller is going to be processed, serving to adjust the uplink-downlink configuration in LTE.

- SDN controllers are managed in a distributed way. In other words, each ONU has its own SDN controller.
DIANA - Time Division Duplex (TDD)

- Standard LTE frame has an overall length of 10 ms, and it consists of 10 sub-frames of length 1 ms each.
- There exist seven uplink-downlink configurations.
- The First and the sixth sub-frames are always for downlink transmission. ‘S’ represents switching. When switching from downlink to uplink, a switching sub-frame is required.

<table>
<thead>
<tr>
<th>Downlink-to-uplink Configuration</th>
<th>Subframes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>D-S-U-U-U-D-S-U-U-U</td>
</tr>
<tr>
<td>1</td>
<td>D-S-U-U-D-D-S-U-U-D</td>
</tr>
<tr>
<td>2</td>
<td>D-S-U-D-D-D-S-U-D-D</td>
</tr>
<tr>
<td>3</td>
<td>D-S-U-U-U-D-D-D-D-D</td>
</tr>
<tr>
<td>4</td>
<td>D-S-U-D-D-D-D-D-D-D</td>
</tr>
<tr>
<td>5</td>
<td>D-S-U-D-D-D-D-D-D-D</td>
</tr>
<tr>
<td>6</td>
<td>D-S-U-U-U-D-S-U-U-D</td>
</tr>
</tbody>
</table>
Summarized in one sentence:

- The real uplink and downlink data transmitted during current LTE frame collected at the end of the current LTE frame, together with the data collected for previous LTE frames can be used to predict the configuration of next LTE frame.
DIANA – Learning Process

- Probability vector of LTE frame \( f \) at ONU-eNB \( i \):
  \[
P^i(f) = \{p_0^i(f), p_1^i(f), \cdots, p_6^i(f)\}
\]
  \[
  \sum_{j=0}^{6} p_j^i(f) = 1
\]

- Downlink-to-uplink ratio for each configuration:
  \[
  p_j^i(f) = 1/7, \forall i, j, 1 \leq i \leq N, 0 \leq j \leq 6
  \]
  \[
  R = \{r_0, r_1, \cdots, r_7\}
\]

- Calculate downlink-to-uplink real traffic ratio for LTE frame \( f \) at ONU-eNB \( i \) at the end of LTE frame \( f \):
  \[
  r^i = r_d^i(f) / r_u^i(f)
  \]

- Find the closet configuration to the real traffic ratio for current LTE frame \( f \):
  \[
  \text{argmin} = \{\|r^i - r_s\|\}
  \]
DIANA – Learning Process

- Penalize rest of the configurations:
  
  \[ p_j^i(f + 1) = p_j^i(f) - W(p_j^i(f) - a), \forall j, 0 \leq j \leq 6, j \neq s \]

  \( W \) and \( a \) are learning parameters.

- Reward the closet configuration to the real traffic ratio for current LTE frame \( f \):

  \[ S = W \cdot \sum_{q=0, q \neq s}^6 (p_q^i(f) - a) \]

  \[ p_{s}^i(f + 1) = p_{s}^i(f) + S \]

- Select the configuration with largest probability for the next LTE frame \( f+1 \):

  \[ \arg\max_n = \{ p_n^i(f + 1) \} \]
Simulation Setup

- XG-PON-LTE-A network was implemented using the LTE system Toolbox in Matlab.
- OLT is connecting to 8 ONU-eNBs.
- Pure Status Reporting (PSR) scheme was adopted, where each ONU-eNB reports its (uplink) queue occupancy to the OLT to determine the bandwidth allocation.
- \( W = 10^{-2} \) and \( a = 10^{-4} \).
- Default uplink-downlink configuration was 1.
- In VoIP traffic setting, each UE has a probability of 80% of initializing a VoIP session upon its connection establishment with the corresponding ONU-eNB. The VoIP session generates about 5.5 and 53 Kbps in the upstream and the downstream direction respectively.

### Scenario 1: Downlink Reference Channel Options

<table>
<thead>
<tr>
<th>Channel Bandwidth</th>
<th>Modulation</th>
<th>Target Coding Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz</td>
<td>16QAM</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td>50 Resource Blocks</td>
<td></td>
</tr>
</tbody>
</table>


Results

- VoIP downstream latency
- VoIP upstream latency
- VoIP jitter
Thank you!