PRECISE: Power Aware Dynamic Traffic Steering in Tightly Coupled LTE Wi-Fi Networks

Thomas Valerrian Pasca S, Himank Gupta, Bheemarjuna Reddy Tamma and Antony Franklin A

Department of Computer Science and Engineering
Indian Institute of Technology - Hyderabad
Outline

1. Introduction
2. Challenges in C-LWIP Architecture
3. Proposed Solution
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   - GI Phase
   - PRECISE
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Mobile data traffic growth is exploding and it will reach 35 Exabytes per month by 2020 [1]

Telco providers/operators face challenges in order to improve their network capacities

Utilizing unlicensed band efficiently has gained operator interest for the increasing their bandwidth

Offloading traffic from cellular network to Wi-Fi network has become operator sweet spot for handling the demand

We focus on LWIP for harvesting the benefits of unlicensed band
Multi RAT Aggregation

- Application layer aggregation (eg., Samsung boost)
- Transport layer aggregation (eg., MPTCP)
- IP layer aggregation loosely coupled (eg., PMIP, ANDSF)
- IP layer aggregation tightly coupled (eg., LWIP)
LTE Wi-Fi interworking

1Ref: Intel presentation at TSDSI
LWIP Architecture

- LWIP has following benefits
  - Wi-Fi operations are controlled directly via LTE base station (eNB) and therefore LTE core network (i.e., Evolved Packet Core (EPC)) need not manage Wi-Fi separately
  - Radio level integration allows effective radio resource management across Wi-Fi and LTE links
  - LTE acts as the licensed-anchor point for any UE, providing unified connection management with the network
- LWIP has finer level of control on radio interfaces, for making efficient steering decision

Figure: C-LWIP Architecture
Challenges in C-LWIP Architecture

- Co-tier interference due to densification of small cells
- QoS provisioning for users in high interference zone
- Independent deployment of LTE and Wi-Fi nodes results in poor interference mitigation
- Steering the traffic across LTE and Wi-Fi alone does not suffice.
Proposed Solution - PRECISE

- **Two Phase of Optimization i.e. IM Phase and GI Phase**
  - **IM Phase**: Sets the Optimal transmit Power for LTE and Wi-Fi interfaces to avoid co-tier interference
  - **GI Phase**: Sets the transmit power of LTE and Wi-Fi interface in order to meet the GBR requirements
- **Steering**: Efficient traffic steering to aggregate the link benefits
Interference Mitigation (IM) Phase I

- Maximize the SINR for the users by varying the power of LTE and Wi-Fi links
- A fractional frequency reuse pattern of LTE and Wi-Fi coverage maximizes the users SINR

\[
\text{Maximize } \Theta^{IM} = \sum_{i=1,j=1}^{U,B} \left( \alpha_{i,j}^L \times \text{SINR}_i^L + \alpha_{i,j}^W \times \text{SINR}_i^W \right) \quad (1)
\]
Interference Mitigation (IM) Phase II

\[ s.t. \]

\[ \sum_{j=1}^{B} \alpha_{i,j}^L \leq 1 \quad \forall i \quad \text{and} \quad \sum_{j=1}^{B} \alpha_{i,j}^W \leq 1 \quad \forall i \]  

\[ \alpha_{i,j}^L = \begin{cases} 
1, & \text{if } \text{SINR}_i^L \geq \text{Th}_{\text{LTE}} \\
0, & \text{otherwise} 
\end{cases} \]  

\[ \alpha_{i,j}^W = \begin{cases} 
1, & \text{if } \text{SINR}_i^W \geq \text{Th}_{\text{Wi-Fi}} \\
0, & \text{otherwise} 
\end{cases} \]  

\[ \alpha_{i,j}^L = \begin{cases} 
0 \text{ or } 1, & \text{if } \alpha_{i,j}^W = 1 \\
0, & \text{otherwise} 
\end{cases} \]  

\[ \alpha_{i,j}^W = \begin{cases} 
0 \text{ or } 1, & \text{if } \alpha_{i,j}^L = 1 \\
0, & \text{otherwise} 
\end{cases} \]  

\[ P_{\text{min}}^L \leq P_j^L \leq P_{\text{max}}^L \quad ; \quad P_{\text{min}}^W \leq P_j^W \leq P_{\text{max}}^W \]
Proposed Solution

GBR Improvement (GI) Phase

Objective function maximizes the weighted SINR function where weight is proportional to number of unsatisfied GBR

Maximize $\Theta^{GI} = \sum_{i=1}^{U,B} \left( r_{i,j}^L \times SINR_i^L + r_{i,j}^W \times SINR_i^W \right)$  

s.t.

\[
\begin{align*}
&\quad \begin{cases}
SINR_i^L - (\gamma \times \Theta(SINR_i^L)) \geq 0 & \text{if } \Theta(SINR_i^L) \geq S_M \\
SINR_i^L - \Theta(SINR_i^L) \geq 0 & \text{otherwise}
\end{cases} \\
&\quad \begin{cases}
SINR_i^W - \gamma \times \Theta(SINR_i^W) \geq 0 & \text{if } \Theta(SINR_i^W) \geq S_M \\
SINR_i^W - \Theta(SINR_i^W) \geq 0 & \text{otherwise}
\end{cases}
\end{align*}
\]

\[P_{min}^L \leq P_j^L \leq P_{max}^L; \quad P_{min}^W \leq P_j^W \leq P_{max}^L\]
Traffic Steering : TOPSIS

**Input:** Set of all flow ($F_i$) parameters, Link to which flow affinity has to be obtained

1. Vector Normalization of all flow parameters $F_{i,j}$ where $i \in \{\text{flows } 1, \ldots, k\}$, $j \in \{\text{network parameters}\}$
2. Apply given set of weights $w^T = \{w_1, \ldots, w_n\}$
3. $F_{i,j} \leftarrow F_{i,j} \times w_j$
4. Find $A^+$ (Positive ideal solution) and $A^-$ (Negative ideal solution)
5. Find Positive ideal separation ($S^+$) and Negative Ideal separation ($S^-$)
6. Calculate $C_i$ for each flow: $C_i \leftarrow \frac{S_i^-}{S_i^+ + S_i^-}$
7. $\mathcal{AI} \leftarrow$ sort $\{C_i\}$ in descending order
8. Return the flow affinity index $\mathcal{AI}_i$ for every flow $F_i$
Proposed Solution

**Start**

**For every 't' msec**

**Obtain all Flow Parameters**

**G^3 >= 90%**

**Trigger GI Phase**

Steer unmet GBR flows to Wi-Fi

**Is GBR unmet?**

Steer set of NGBR flows with high AI to Wi-Fi

**TOPSIS**

Load LTE > Load Wi-Fi

**Is GBR unmet?**

Steer set of NGBR flows with high AI to LTE

**Start**

**Obtain all Flow Parameters**

**G^3 >= 90%**

**Trigger IM Phase**

Steer unmet GBR flows to LTE

**Is GBR unmet?**

Steer set of NGBR flows with high AI to LTE

**Stop**

**After experiment duration**
## Experimental Setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of UEs, LWIP Nodes</td>
<td>100, 4</td>
</tr>
<tr>
<td>Max Tx power of LTE &amp; Wi-Fi</td>
<td>23, 20 dBm</td>
</tr>
<tr>
<td>LTE path loss model</td>
<td>3GPP indoor path loss model</td>
</tr>
<tr>
<td>Wi-Fi path loss model</td>
<td>ITU path loss model</td>
</tr>
<tr>
<td>LTE MAC Scheduler</td>
<td>Priority Set Scheduler (PSS)</td>
</tr>
<tr>
<td>UE position</td>
<td>Random</td>
</tr>
<tr>
<td>UE mobility model</td>
<td>Constant Position Mobility Model</td>
</tr>
<tr>
<td>Wi-Fi Standard</td>
<td>IEEE 802.11n</td>
</tr>
<tr>
<td>Wi-Fi frequency and bandwidth</td>
<td>2.4 GHz, 20 MHz</td>
</tr>
<tr>
<td>LTE frequency and bandwidth</td>
<td>2.6 GHz, 10 MHz</td>
</tr>
</tbody>
</table>
Simulation Setup

- Building of dimension 50m X 50m X 10m
- Building has two floors and a wall per every 10m
- 4 C-LWIP nodes placed with mean euclidean distance between nodes as 20m
- Path loss model includes wall and floor losses

Figure: Building dimension considered for evaluation
SINR Distribution

- SINR distribution observed in following 2 Cases
  - LWIP with fixed power
  - LWIP with optimal power obtained from PRECISE algorithm
- PRECISE has improved SINR of UEs by 4 dB in both LTE and Wi-Fi links
- This improvement in SINR is due to optimal power control

Figure: CDF of UE SINR.
Ensure GBR in the network

- When no of flows are 100, IM phase is triggered more frequently since there are less unsatisfied GBR flows.
- As number of flows increases, more GI Phase is triggered more which regulates the transmit power inorder to reduce unsatisfied GBR Flows.

Figure : Events triggered for varying load.
In every 200 msec either of IM Phase or GI Phase will be triggered.

As number of flows increases from 100 to 600, the number of IM Phase trigger reduces since more unsatisfied GBR flows exists.

PRECISE instantiates more GI triggers to reduce unmet GBR flows.

Figure: Triggers for different threshold.
Throughput Analysis

- CDF of UEs throughput observed for a fixed number of Flows i.e 600.
- Rel-12 ensures that UE is associated with best interface and flows are routed through it.
- $\alpha$-Optimal only steer the flows across interface proportionally fair based on link rates.
- PRECISE regulates the transmit power and also enables flow steering across best interface.

Figure: CDF of UEs throughput.
Throughput Analysis (contd.)

Figure: Throughput for different load.

Figure: Unsatisfied GBR.
Throughput and GBR Analysis

- Performances of different algorithms are compared with PRECISE algorithm for 600 Flows.
- PRECISE algorithm has improved the network throughput by 48% and 84 % as compared to $\alpha$-optimal Algorithm and 3GPP REL-12 respectively.
- PRECISE algorithm minimizes the unmet GBR flows compared to other algorithms because of PRECISE algorithm regulates the transmit power of LWIP node and steer the flows to best available interface. While $\alpha$-optimal only steer the flows and Rel-12 choose the interface based on best SINR available.
- PRECISE algorithm has reduced the number of GBR flows unmet by 35% as compared to $\alpha$-optimal scheduler.
Conclusions and Future Directions

- Co-located LWIP enables sophisticated control over LTE and Wi-Fi RATs.
- PRECISE algorithm thrives to ensure QoS and maximizes throughput in co-located LWIP deployment scenario.
- PRECISE algorithm employs power control for interference mitigation and to enhance GBR throughput of UEs with poor SINR.
- PRECISE supports dynamic flow steering using MADM technique in order to improve the network throughput.
- PRECISE outperformed throughput of $\alpha$-optimal scheduler by 48% and 3GPP Rel-12 interworking by 84%.
- PRECISE reduced the number of unmet GBRs by 35% compared to $\alpha$-optimal scheduler.
- PRECISE can be optimized further to improve UE battery savings.
Acknowledgements

This work was supported by the project "Converged Cloud Communication Technologies"

Ministry of Electronics and Information Technology
Government of India


