Application-aware Cross Layer Design: Top-down Approach

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Summary
Motivation of CLD
- Solution for the Inefficient Activity of a System

CLD Basic Concept
- Share the Infor.
  - Control the Func.
  \{ Inter-layer \}

Objectives of CLD
- QoS Provisioning
- System Performance Enhancement

Main Ex. of CLD
- QoS Scheduler
- Band Adaptive Modulation Coding (AMC): IEEE 802.16 Systems, WLAN, etc.
- Wireless TCP
CLD for QoS Provisioning

- **Concept**
  - For the QoS provisioning, it may be needed that each layer has to take action in order to meet the QoS requirement.

- **Main CLD for QoS Provisioning**

- **QoS Requirement** (delay, PER, etc)

- **Wireless Channel**
  - PHY
  - MAC
  - CS
  - IP
  - TCP/UDP
  - Application

- **Congestion**

- **Backbone Network**

- **Corresponding Node**

- **Full Buffer**

- **Delay Insensitive Service**: TCP
- **Delay Sensitive Service**: UDP
For the QoS provisioning, it may be needed that each layer has to take action in order to meet the QoS requirement.

Priority based Scheduling (PQ, DPS, WFQ, etc)
CLD for QoS Provisioning

- **Concept**
  - For the QoS provisioning, it may be needed that each layer has to take action in order to meet the QoS requirement.

- **Main CLD for QoS Provisioning**

  - **Polling/Reservation**: Sensitive to Delay
  - **Contention**: Insensitive to Delay

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**Wireless Channel**

- **PHY**
- **MAC**
- **CS**
- **IP**
- **TCP/UDP**
- **Application**

- **QoS Requirement** (delay, PER, etc)

**Polling/Reservation**

- **Packet**
- **GI**
- **PI**
- **Random Access**

**Contention**

- **Packet**
- **Collision**
- **backlogged**
- **Success**

---

**Wireless Network**

- **Corresponding Node**
CLD for System Performance

Concept

- BandAMC
  - High SNR: High Modulation and Low Coding
  - Low SNR: Low Modulation and High Coding

- MIMO
  - Diversity Gain: Reliability
  - Multiplexing Gain: Throughput
CLD for System Performance

- **Concept**
  - In order to improve the **system performance**, the interworking to **compensate the inefficient action** between layers is needed.

- **Main CLD for System Performance**

  - **Opportunistic Scheduling (PF, Max. C/I)**
    - Increases the Cell Throughput
Concept

- In order to improve the system performance, the interworking to compensate the inefficient action between layers is needed.

Main CLD for System Performance

- Routing Algorithm for Reliability
  - Channel, Distance, BW Information, etc

\[
P_i = \arg \max \left( \sum_j CQI_j \right) \\
\text{\(i\): path index, \(j\): node index in path \(i\)}
\]

\[
P_i = \arg \min \left( \sum_j \text{distance}_j \right) \\
\text{\(i\): path index, \(j\): node index in path \(i\)}
\]

\[
P_i = \arg \max \left( \sum_j \text{BW}_j \right) \\
\text{\(i\): path index, \(j\): node index in path \(i\)}
\]
CLD for System Performance

- **Concept**
  - In order to improve the **system performance**, the interworking to **compensate the inefficient action** between layers is needed.

- **Main CLD**

  ![CLD Diagram]

  - **SNR**
  - **Frequency**
  - **Packet Loss**
  - **No Congestion**
  - **TCP Timeout → Retransmission??**
  - **Pathloss, shadowing, multipath fading**
  - **Channel Infor.**
  - **Wireless TCP**

  ![Layer Diagram]

  - **Application**
  - **TCP/UDP**
  - **IP**
  - **CS**
  - **MAC**
  - **PHY**
  - **Wireless Channel**
CLD for System Performance

- **Concept**
  - In order to improve the system performance, the interworking to compensate the inefficient action between layers is needed.

- **Main CLD**

  - **Application Rate:**
    - Rate1 > Rate2 > Rate3

  - Rate Control based on Channel Condition (AMR, EVRC)

  - Channel Information

  - Pathloss, shadowing, multipath fading

  - Backhaul Network

  - Corresponding Node

  - Wireless Network
## Summary of Conventional CLD

### CLD for QoS Provisioning

<table>
<thead>
<tr>
<th>Layer</th>
<th>Functions</th>
</tr>
</thead>
</table>
| App. Layer | • Congestion Control and Flow Control (TCP)  
• Fast Tran. (UDP) |
| TCP/UDP | • QoS Scheduler (DPS, PQ, WRR, etc) [1]  
• QoS Queue Management (WRED) [2]  
• QoS Routing Algo. [3], [4] |
| IP | • BW Request Scheme (polling/reser./contention) [5]-[8]  
• QoS based Opportunistic Scheduling [9]  
• QoS based ARQ [10],[11] |
| MAC | • Distance, Channel, L2 BW based Routing Algo. [15]-[17] |
| PHY | • PHY Channel based Encoding Tech. (AMR, EVRC, Video) [12],[13]  
• Wireless TCP [14]  
• Fast L2 Handover [18],[19]  
• Opportunistic Scheduling Algo. (Max. C/I, PF) [20]-[22] |
| System Efficient Scheme for the Application Traffic | QoS Provisioning ?? |

### CLD for System Performance Enhancement

<table>
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<tr>
<th>Layer</th>
<th>Functions</th>
</tr>
</thead>
</table>
| IP | • QoS Scheduler (DPS, PQ, WRR, etc) [1]  
• QoS Queue Management (WRED) [2]  
• QoS Routing Algo. [3], [4] |
| MAC | • Distance, Channel, L2 BW based Routing Algo. [15]-[17] |
| PHY | • PHY Channel based Encoding Tech. (AMR, EVRC, Video) [12],[13]  
• Wireless TCP [14]  
• Fast L2 Handover [18],[19]  
• Opportunistic Scheduling Algo. (Max. C/I, PF) [20]-[22] |

### Strategy: Improve the System Efficiency in the View of the Application Layer (User-Perceived)

**Application-aware CLD for System Efficiency Enhancement**
Concept of Application-aware CLD

Motivation

- Consideration Priority in Development Process
  - User-perceived QoS Performance
  - System Efficiency

CLD Sequence

1. Investigate QoS Provisioning Mechanism to Meet the QoS Requirement
2. Study on the System Efficiency Enhancement Considering the Application Traffic Features based on the QoS Provisioning Mechanism for each layers

Top-down Approach

1. TCP/UDP, IP, MAC, PHY are efficient ?
2. Optimization between QoS provisioning and system efficiency is needed ?

<table>
<thead>
<tr>
<th>Traffic Features</th>
<th>QoS Requir.</th>
</tr>
</thead>
</table>
| VoIP             | • < 150 ms (one-way delay)  
                   • < 3% FER  
| Video            | • Videotele. < 150 ms (one-way delay)  
                   • Videotele  
| Web              | • < 4 s per Page (one-way delay)  
                   • zero FER  
| FTP              | • Bulk arrival (File request, File Down.)  
                   • zero FER  
| Video           | • Variable Packet Size based on Pattern (MPEG4)  
                  • Periodically Generated  

Reference: 3GPP TSG-SA Working Group 1, TSGS1#4(99)529, 5-9 July 1999
Network functionalities can be allocated
- How to optimally allocate network functionalities?

**Vertical Optimization**
- Application
  - TCP/UDP
  - IP
  - PPP
  - MAC
  - Ethernet
- Airlink
- T1/E1
- HDLC

**Horizontal Optimization**
- IP
- RMI
- TCP/UDP
- GRE
- L2
- Phys

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10 Base T Cable
Router
Backhaul
R-P (A10/A11)
IP Network

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GRE - Generic Routing Encapsulation (protocol)
TCP - Transmission Control Protocol
HDLC - High Level Data Link Control
UDP - User Datagram Protocol
IP - Internet Protocol
PPP - Point-to-Point Protocol
Network Utility Maximization

- **Decomposition method**
  - **Divide the optimization problem into sub-problem**
    - **Vertical decomposition** (optimization)
      - Decomposed *subproblem* → Layer
      - Function of primal or Lagrange dual *variables* → Interfaces among the layers
    - **Horizontal decomposition** (optimization)
      - Geographically separation of the functionality module
  - **Example (Flow control)**
    - **Horizontal decomposition**
      - Each users(Greedy!!) want to increase its data rate
      - Increased data rate cause the network congestion
      - Server(rate control by penalty) and Router(penalty control by rate)
Network Utility Maximization

- **Objective Function**
  - Who is interested in the outcome?
    - Sum of utility functions by *end users*
    - Network-wide cost function by *network operators*
  - What is interested?
    - Sum utilization maximum: maximizing a weighted sum of all utility functions
    - Game theory: Compete between users and operators or among users
  - Example (Flow control)
    - Sum Utilization Maximum
      - If $x_r$ is the rate on router $r$, then the utility to user $r$ is $U_r(x_r)$
      - $U_r(x_r)$: Increasing, strictly concave, continuously differentiable

\[
\max \sum_{i=1}^{3} \log(x_i)
\]
Network Utility Maximization

- **Constraint set of a NUM formulation**
  - Technological, and economic restrictions
    - Network capacity
  - Per-user, hard, inelastic QoS constraints
    - Delay bound, Minimum rate, etc.

- **Example (Flow control)**
  - Technological restrictions
    - Sum of inputs is less than the capacity
  - QoS constraints
    - Each users want to be served greater than 0 rate

Technological restrictions

\[ x_1 + x_2 \leq C_1 \]
\[ x_1 + x_3 \leq C_2 \]

QoS constraints

\[ x_i \geq 0 \quad \forall i \]
Part II: Application-aware Cross Layer Design in BWA Networks
VoIP Codec based Dynamic UL BW Req./Allo. Scheme

**Motivation**
- Main QoS Requirement: Sensitive to delay requirement
- Main Traffic Features of the VoIP Service: VoIP traffic rate is variable
  - Repetition of the Cycle of the talk-spurt and silent-period
  - Talk-spurt: traffic rate can be variable according to the network condition (AMR, EVRC)
  - Silent-period: Silence descriptor (SID) frame can be generated with different period or random interval
- History of the UL BW Req./Allo. Scheme for VoIP Service

<table>
<thead>
<tr>
<th>To meet delay requirement</th>
<th>To improve the system efficiency (ON/OFF period)</th>
<th>To improve the system efficiency (Traffic Rate Variable in Talk-spurt)</th>
<th>To improve the system efficiency (Traffic Rate Variable in Silent-period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Persistent BW Allo. Scheme (UGS in DOCSIS)</td>
<td>- Dynamic BW Allo. Scheme (UGS-AD in DOCSIS and rtPS in IEEE 802.16)</td>
<td>- Dynamic BW Allo. Scheme (ertPS in IEEE 802.16e)</td>
<td>- ???</td>
</tr>
</tbody>
</table>
VoIP Codec based Dynamic UL BW Req./Allo. Scheme

- For the AMR Speech Codec
  - Main Traffic Features: Talk-spurt 20msec, Silent-period 160msec

**Conventional ertPS**

**Proposed**

Interworking between App. and MAC
- Detect the VoIP Speech Codec in App.(AMR)
- Use the VAD of VoIP Speech Codec
- Separated Action due to VAD
  - Dynamic Grant Interval
  - Dynamic Grant Size

```
if codec == AMR then
  if VAD == Talk-spurt then
    Grant for every 20 msec;
  else
    Grant for every 160 msec;
  end if
end if
```
VoIP Codec based Dynamic UL BW Req./Allo. Scheme

- Numerical Results
  - VoIP Capacity: maximum number of supportable VoIP users
  - Throughput: Received bits per second

The proposed algorithm can increase the VoIP capacity by 26% compared to the conventional ertPS

User-perceived QoS Enhancement for VoIP Service in BWA Networks

- **Motivation**
  - In wireless networks, packet loss can affect the QoS performance for VoIP services.
  - In BWA networks, retransmission scheme has been defined to overcome the packet loss.

- **Main Question**
  - Is it a good solution that the retransmission scheme is applied to the VoIP service in order to overcome the packet loss due to the channel fading?

- **QoS Requirement of the VoIP Service (delay ↓ and packet loss rate ↑)**
- **Retransmission Scheme (delay ↑ and packet loss rate ↓)**

Evaluate based on the **User-perceived QoS Performance** (MOS or R-value)

- Build the end-to-end performance evaluation simulator
- Measure the $d_{\text{network}}$ and $e_{\text{network}}$ by using the simulation
- Calculate the R-value ($R$) and MOS
User-perceived QoS Enhancement for VoIP Service in BWA Networks

- Performance Evaluation
  - SNR in PHY
  - Application throughput and delay

**Communication Channel Environment**

**Performance Results in Application Layer**

![Graphs showing SNR vs Simulation Time and Throughput vs Simulation Time]
User-perceived QoS Enhancement for VoIP Service in BWA Networks

Performance Evaluation

- MOS (Mean Opinion Score): User-perceived QoS Performance
  - UGS: cannot request the additional BW for retransmission
- Number of used slots: Includes the retransmission packets

**Optimization Problem**
- Optimal $k$
- System Efficiency ($SE$)
- User-perceived QoS Performance ($Q$)

$$\max_k SE(k)$$

$$Q(k) \subset Q$$

- QoS performance $\uparrow \rightarrow$ Resource Consumption $\uparrow \rightarrow$ System Efficiency $\downarrow$

Video Codec based Dynamic UL BW Req./Allo. Scheme

- **Motivation**
  - QoS Requirement: Video Telephony (delay < 50 msec in wireless networks)
  - Main Traffic Feature for MPEG4: Repetition of the Group of Picture (GOP) pattern (I frame, B frame, P frame)
    - I frame: ave. 4742 bytes, min 4034, max 5184
    - B frame: ave. 147 bytes, min 35, max 882
    - P frame: ave. 259 bytes, min 100, max 1663

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**rtPS**
- Access Delay: > 20 msec

**ertPS**
- Large Wasted Resource

**Proposed BWReq./Allo. Scheme**
- Large Difference Size among the I, B, and P Frame

**Merits**
- Efficiently Use the BW
- Reduce the Access Delay
Video Codec based Dynamic UL BW Req./Allo. Scheme

- Simulation Results
  - Normalized Resource Utilization (%): Resource for information / Total resource
  - Ave. Access Delay (msec): Average time to send a video frame from SS to BS

The proposed algorithm can efficiently use the radio resource by about 99% and send a video frame with average access delay 11 msec.

Novel BW Req. Scheme for BE Services to Improve the System Efficiency

- **Motivation**
  - Main Traffic Feature: **Insensitive** to delay requirement
  - Conventional BW Req. Scheme: **Random Access**
  - History of the BW Req. Scheme for BE Services in BWA Networks

**Random Access**

- **Direct Contention Scheme**
  - Pure Aloha
  - Slotted Aloha

- **Indirect Contention Scheme**
  - Short Message BW Req. Scheme (DOCSIS, IEEE 802.16)
  - **collision resolution algo.**
  - Binary Exponential Backoff Algo. (DOCSIS, IEEE 802.16)

Should we **immediately** request the required BW for BE service ???

It may be **NO**

- It is possible that a BE packet is sent **without contention**.
- The **system overhead** for BW req. can be **reduced**.
Novel BW Req. Scheme for BE Services to Improve the System Efficiency

- For the Ranging Mechanism
  - Uplink periodic ranging is required to maintain a connection

**Conventional ertPS**

<table>
<thead>
<tr>
<th>Initial Ranging Opportunities</th>
<th>Request Contention Opportunities</th>
<th>SS 1 Scheduled Data</th>
<th>SS N Scheduled Data</th>
</tr>
</thead>
</table>

- **BW Req. Slot is needed**

**Proposed**

- BW Req. with **Uplink Periodic Ranging**
- **Merits**
  - Avoid the Contention
  - Reduce the System Overhead for the BW Req.

**Algorithm 1 Proposed Bandwidth Request Algorithm**

Require: \( e \in \{ERROR \text{ or } NO\_ERROR\} \) and \( q_{BE} \geq 0 \)

1: An SS checks an error of all received packets: \( e \)
2: An SS checks the BE queue: \( q_{BE} \)
3: A BS allocates a bandwidth by the uplink periodic ranging
4: if \( e = ERROR \) then \{Action of the SS\}
5:   if \( q_{BE} > 0 \) then
6:     Send a RNG-REQ message with BW-REQ field > 0
7:   else
8:     Send a RNG-REQ message with BW-REQ field = 0
9:   end if
10: else
11:   if \( q_{BE} > 0 \) then
12:     Send a BW-REQ header
13:   else
14:     Wait for the next event
15:   end if
16: end if
Novel BW Req. Scheme for BE Services to Improve the System Efficiency

- Numerical and Simulation Results
  - Uplink throughput: Received bit per second
  - Utilization (for given same traffic load): Used resource / total resource

It can improve the system capacity by 11% compared to that of the conventional system

Reference: 오성민, 김재현, 김봉찬, 김성완 "광대역 무선통신 시스템에서 상향링크 대역폭 요청 장치 및 방법," 국내 특허, 출원일: 2010.02.18 출원번호: P2010-0014505
Three-Layer Interworking Retransmission Scheme

Goal

- Performance Analysis of Three-Layer Retransmission Scheme based on QoS Provisioning

\[ TCP \text{ Throughput} \approx \frac{1}{RTT \sqrt{\frac{2bp}{3}} + T_0 \text{ min} \left(1, 3\sqrt{\frac{3bp}{8}}\right) p \left(1 + 32p^2\right)} \]

\[ D_{\text{trans}} = D_{\text{one way}} + RTT \cdot (\bar{N} - 1) \]

End-to-End Retransmission
Three-Layer Interworking Retransmission Scheme

- Simulation results
  - Performance Comparison for Various Combinations (HARQ, ARQ, TCP)
  - Find out Appropriate Retransmission Scheme based on QoS Requirement

For the application traffic, the selected retransmission set can improve the system efficiency with guaranteeing a QoS.

User-centric Mobility

- User-centric terminal-controlled (network-assisted) seamless mobility
Service Continuity Management Tech.

Objective
- To Provide **Multiple Sessions for a Service** by using **Wireless Multi-homing** Tech.
User-centric Mobility Providing Tech. Results

- Network Architecture for User Centric Wireless Multi Homing
- Simulation result
  - Handover interruption time elimination
  - QoS Guarantee through Multi Homing Tech.

Protocol stack for mobile node

Network Architecture for L2 Based eNB

End-to-End delay

Throughput
Summary

- **CLD Classification**
  - CLD for QoS Provisioning
  - CLD for System Performance Enhancement
  - It is needed to consider the system efficiency for the application traffic

- **Application-aware CLD**
  - System Consideration (from APP. to PHY.) in the View of Application Layer
  - System Efficiency Improvement (Duplicated Tech. Omission, Application Traffic Pattern based Tech.)
  - System Performance Enhancement (CLD with Optimization Theory)
  - Energy Saving (OS, APP., Tran., Net., MAC, PHY., Circuit, etc)


