New Approaches To Next Generation Communication: Cross Layer Design and IDMA

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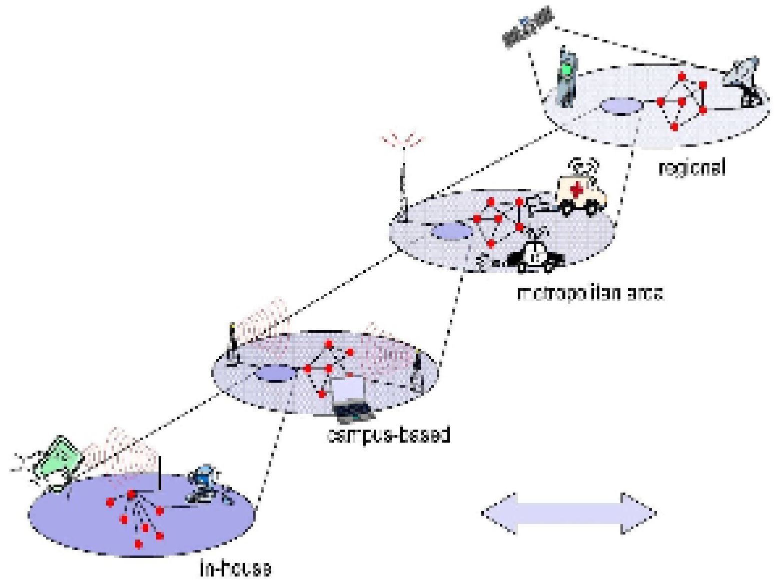
* A joint work by Dongfeng Yuan, Haixia Zhang, Yanbo Ma and Xiaotian Zhou

Contents

Next Generation Communication

- Demands of NGC:
  - Broadband Transmission
  - Multi-media Transmission
  - Supporting High-speed UT
  - Ubiquitous Experience
- Research on NGC
  - Novel Network Framework
    - Cognitive Radio, Cooperative Network, WSN, WiMAX ......
  - Novel Methodology or Technology
    - Cross Layer Design, IDMA, OFDM, Network Coding……

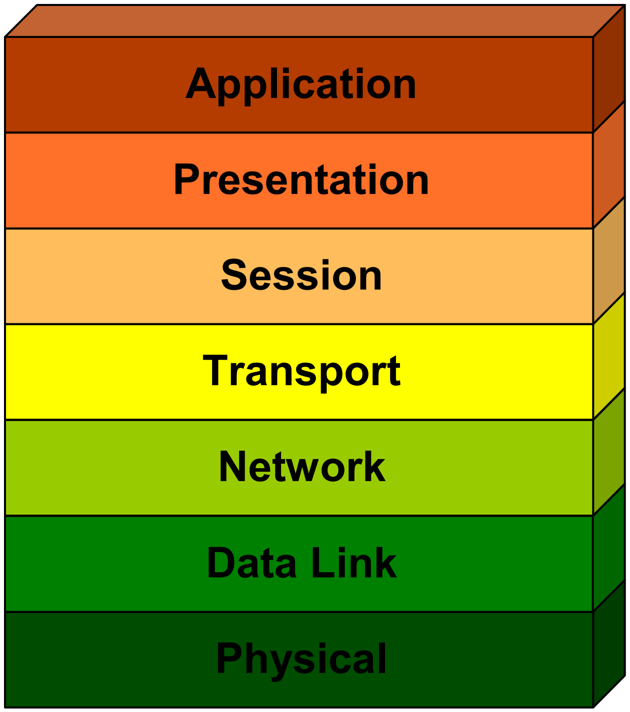


Contents

- Background
- CLD in the Next Generation Communication
  - Concept of Cross Layer Design
  - CLD in Multi-media Sensor Network
  - CLD in Vehicular Communication Networks
- IDMA in the Next Generation Communication
  - Concept of IDMA
  - IDMA in Cognitive Radio Network
- Other Related Work

Concept of Cross Layer Design

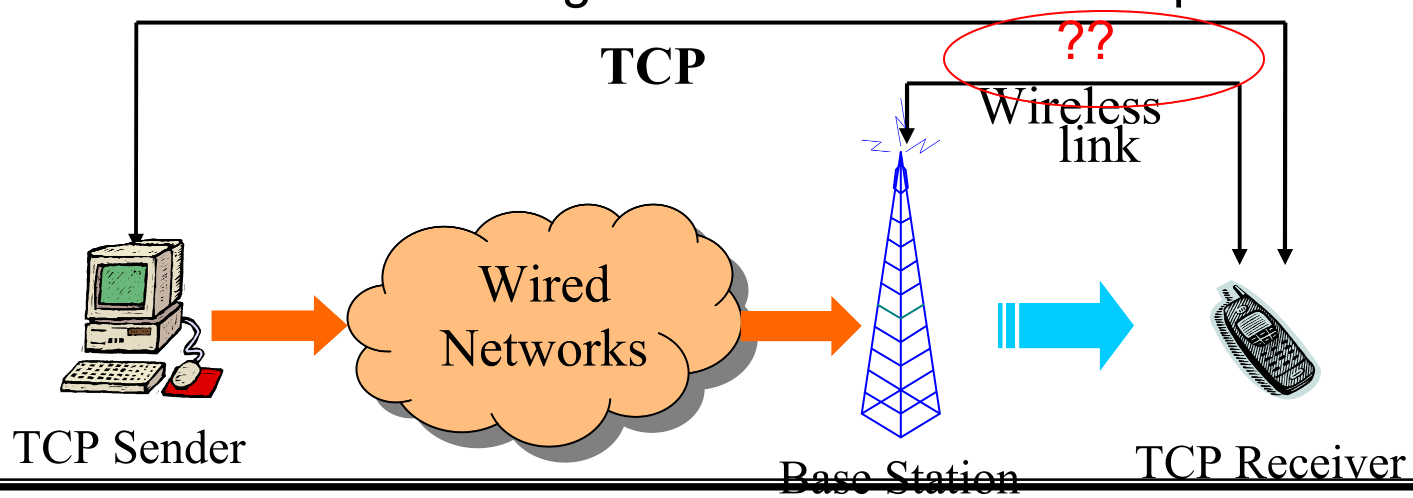
- Why Layered?
  - Simplify the network protocol design
  - Avoid the information exchange between different layer
  - Facilitate the interconnection of different devices
  - Portability in different scenario



The original model is proposed for wired network

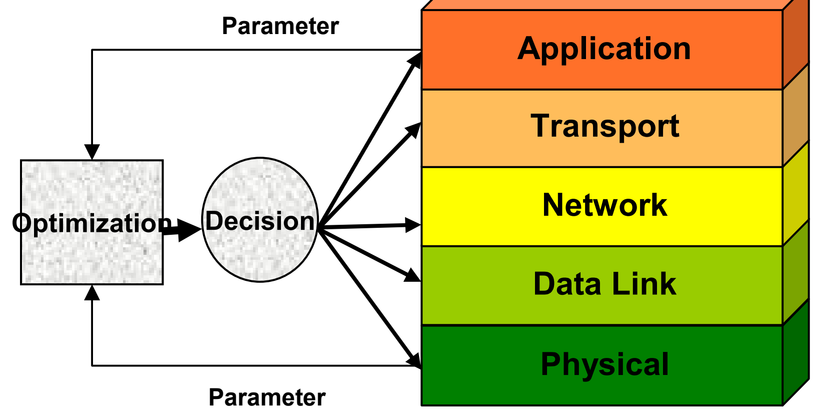
Concept of Cross Layer Design

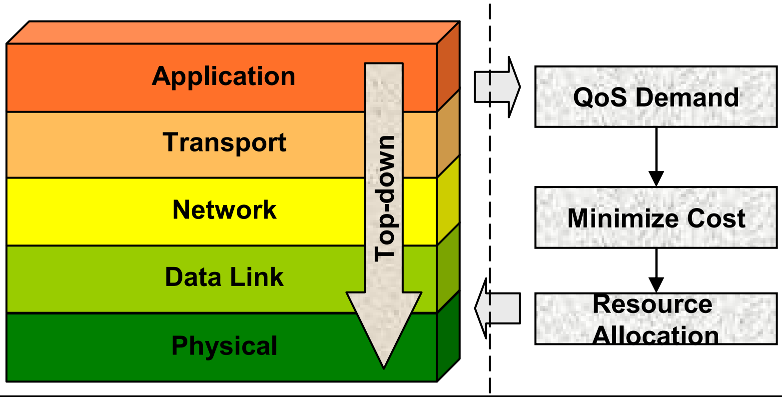
- Drawbacks:
  - Not suitable for time-varying wireless scenario
  - Independently optimization in one layer with respective to its output might lead to a counterproductive results to the other layer
- Example:
  - Packet loss due to fading effect in wireless scenario may be incorrect treated as congestion in traditional TCP protocol

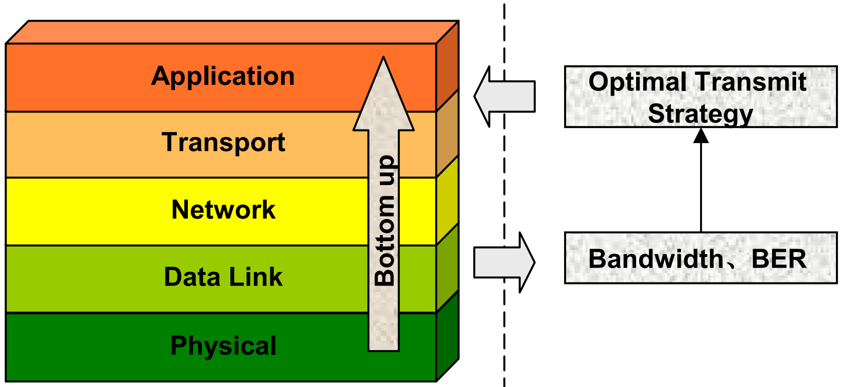


Concept of Cross Layer Design

- Top down CLD
- Bottom up CLD
- Composite CLD







Concept of Cross Layer Design

- Cross Layer Model
  - Effective capacity:
    - describe the queuing behaviors at data link layer
    - characteristic the maximal arrival rate which can be supported under guaranteed delay QoS requirements
  - Mathematical expression

$$E_C(\theta) = \lim_{t\to\infty} -\frac{1}{\theta t} \log E[e^{-\theta \sum_{k=1}^{t} S[k]}]$$

$S[k]$ denotes the service process

θ denotes the delay QoS exponent

$$\Pr\{D(t) \geq D_{\max}\} \approx \delta e^{-\theta^* \mu D_{\max}} \leq \varepsilon.$$

δ non-empty probability of the buffer at link layer

μ rate of source traffic flow

ε maximum delay bound violation probability

Concept of Cross Layer Design

❑ Cross Layer Model

- **Physical layer**

  —resource allocation

- **Data link Layer**

  —queuing

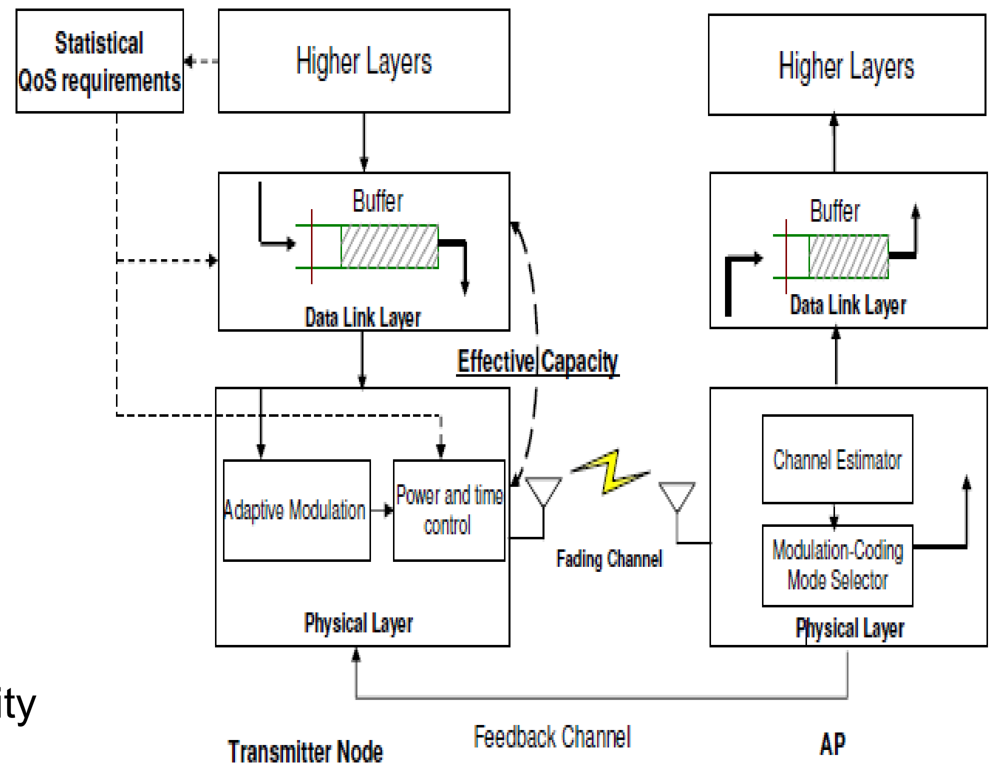
- **Cross Layer information**

  —effective capacity

- **QoS requirement**

  —QoS exponent

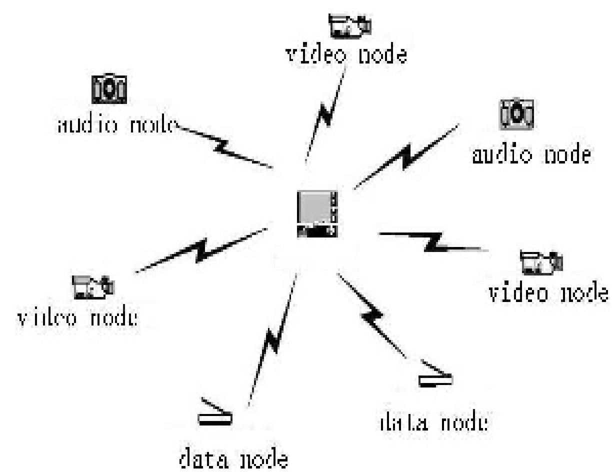
  —delay bound violation probability



CLD in Multi-media Sensor Network*

- Challenge in Multi-media Sensor Network
  - Power constraint at nodes
  - Read-time transmission requirement

- Scenario considered
  - Clustered single hop network
  - MAC：TDMA



* "POWER-EFFICIENT RESOURCE ALLOCATION WITH QOS GUARANTEES FOR TDMA FADING CHANNELS" accepted by Wireless Communications and Mobile Computing

CLD in Multi-media Sensor Network

- Resource Allocation
  - Extend network life: reducing power dissipation while fulfilling the delay QoS requirement of multimedia flow

Minimizing the average transit power while satisfying delay QoS requirements

  - Improve the network capacity： increase the network throughput with QoS requirements

Maximizing the effective capacity with given power constraints

Dual Problem

CLD in Multi-media Sensor Network

- Problem Formulation
  - The resource allocation is formulated as a constrained optimization problem
  - **Optimization objective: minimizing the average transmit power of sensor node**
  - **Constraints**
    - Effective capacity: delay QoS constraint
    - Slot constraint

$$\arg\min_{\boldsymbol{\tau}(\mathbf{h}),\mathbf{r}(\mathbf{h})} \sum_{k=1}^{K} \mathrm{E}\left[\frac{\tau_k(\mathbf{h})}{h_k}\left(2^{r_k(\mathbf{h})/\tau_k(\mathbf{h})}-1\right)\right],$$

Objective Function

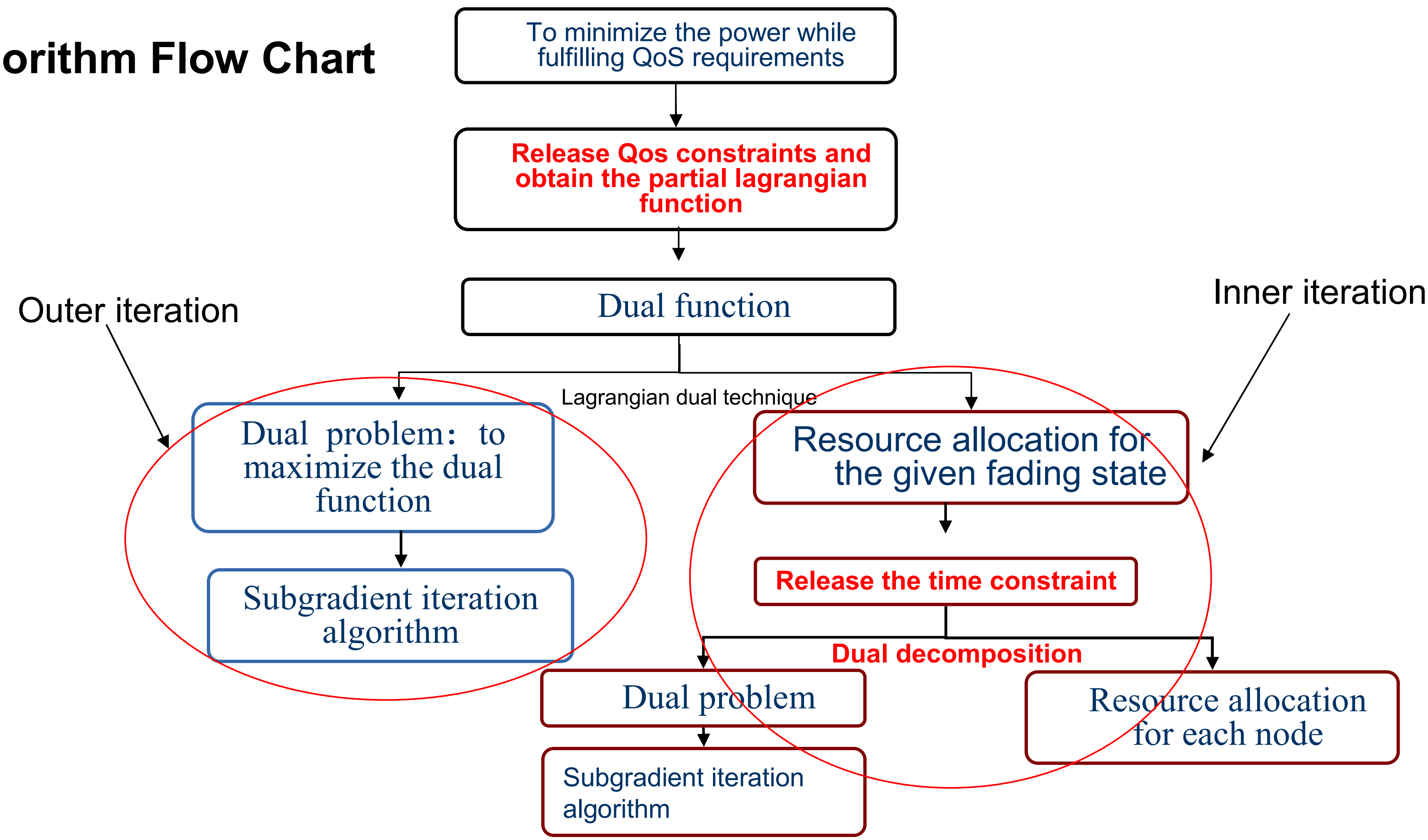
$$\text{s.t.} \quad -\frac{1}{\theta_k}\log\left(\mathrm{E}\left[e^{-\theta_k r_k(\mathbf{h})}\right]\right) \geq E_k, k=1,\ldots,K,$$

Constraints

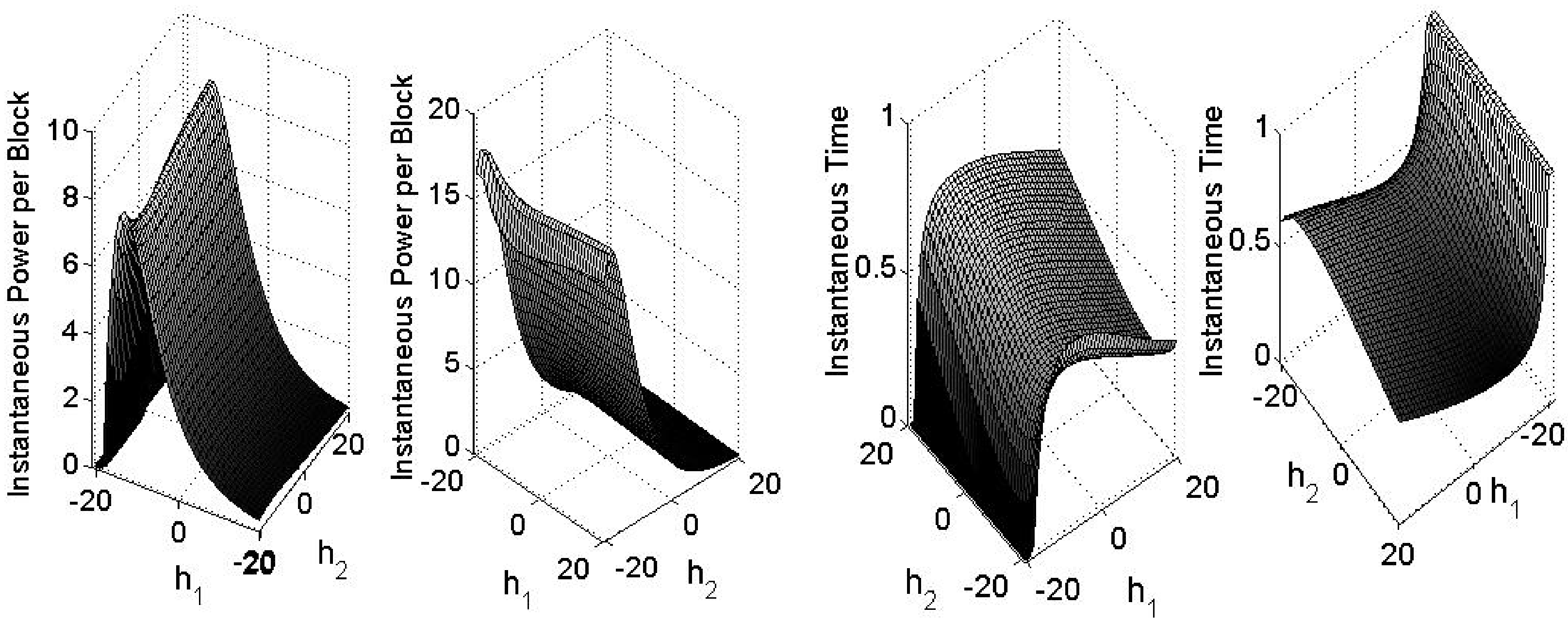
$$\sum_{k=1}^{K} \tau_k(\mathbf{h}) \leq 1.$$

CLD in Multi-media Sensor Network

Algorithm Flow Chart



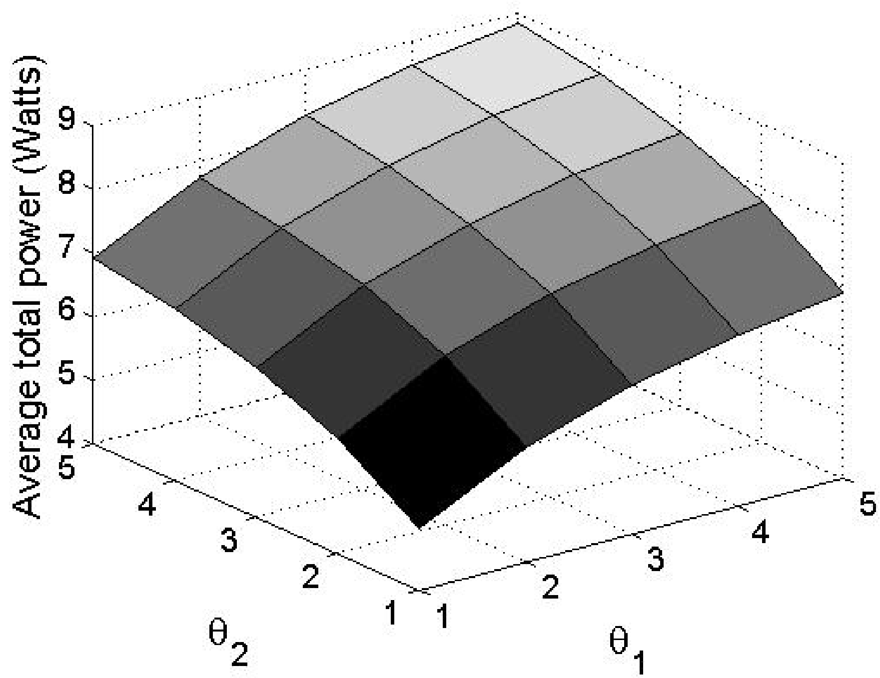
CLD in Multi-media Sensor Network



(a) (b)

- Rayleigh fading channel and $\theta_1 = 2,\ \theta_2 = 3$
- The joint power and time allocation to minimize the average power while fulfilling the given delay QoS requirements
- The power and time allocated to user 2 is larger than those of user 1 under the same channel conditions.

CLD in Multi-media Sensor Network



- The average total power versus delay QoS exponent $\{\theta_1, \theta_2\}$
- The average total power increase with QoS exponent
- Symmetry

CLD in Multi-media Sensor Network

Problem Formulation

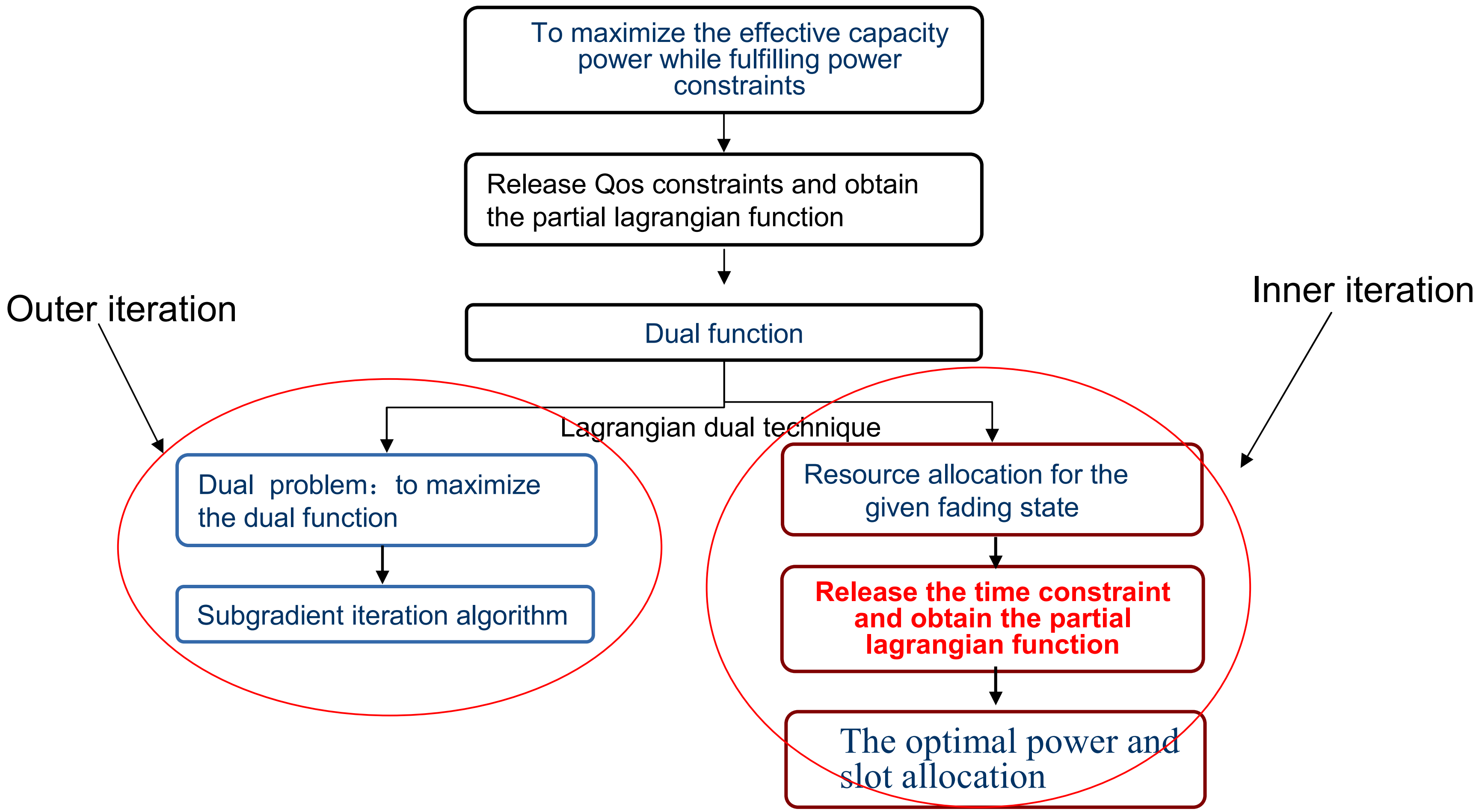
- The resource allocation is formulated as a constrained optimization problem
- **Optimization objective: maximizing the effective capacity of network**
- **Constraints**
  - Power constraint of each node

$$\begin{aligned}
&\arg\max_{\boldsymbol{\tau}(\mathbf{h}),\mathbf{p}(\mathbf{h})} \; -\frac{1}{\theta}\log\left(\mathrm{E}\left[e^{-\theta\sum_{k=1}^{K}\tau_k(\mathbf{h})\log_2(1+h_k p_k(\mathbf{h})/\tau_k(\mathbf{h}))}\right]\right),\\
&\text{s.t.} \quad \mathrm{E}[p_k(\mathbf{h})] \le Q_k, k = 1,\dots,K,\\
&\qquad \sum_{k=1}^{K}\tau_k(\mathbf{h}) \le 1.
\end{aligned}$$

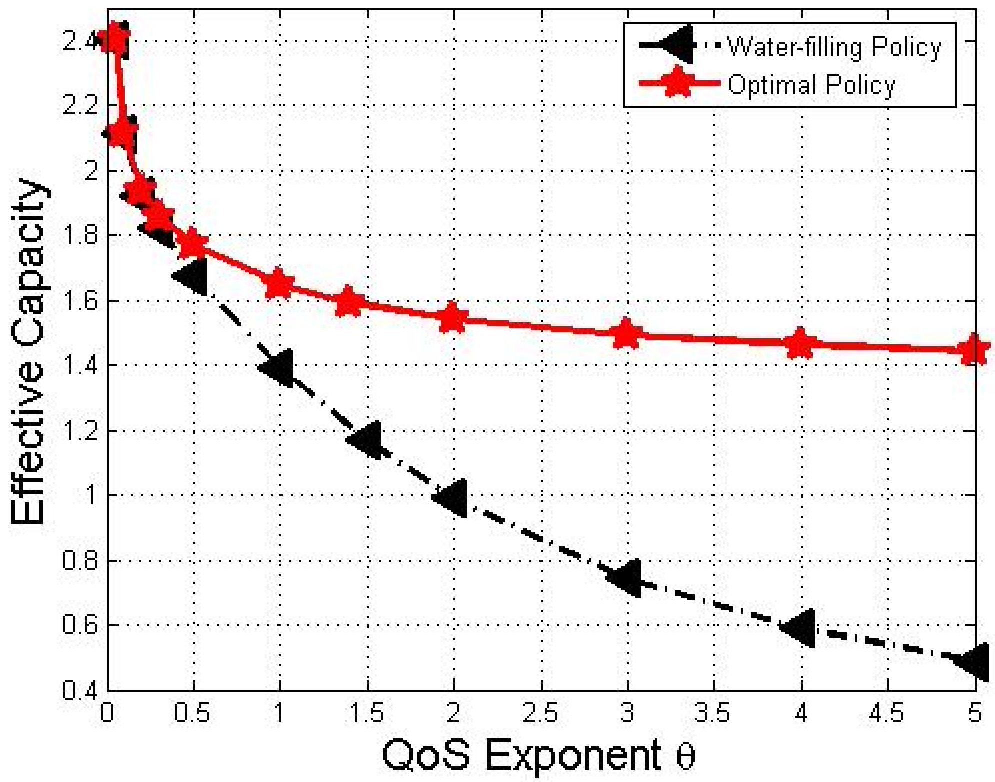
Objective Function

Constraints

CLD in Multi-media Sensor Network



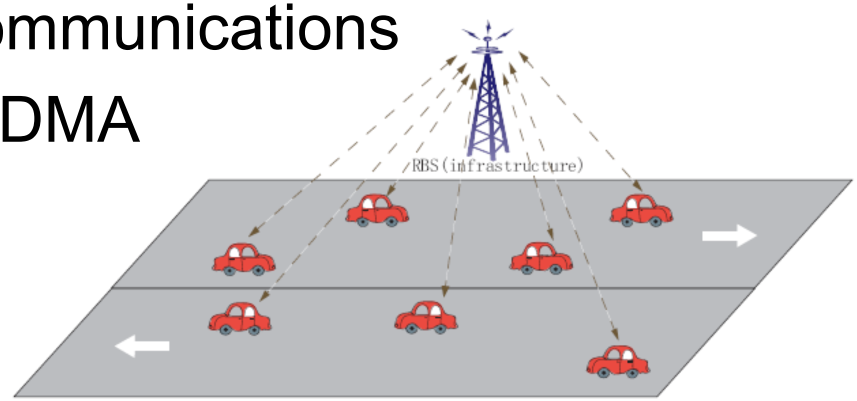
CLD in Multi-media Sensor Network



- Rayleigh fading channel
- The effective capacity versus QoS exponent
- The effective capacity converges to a nonnegative constant

CLD in Vehicular Communication Networks*

- Network scenario
  - downlink channel of V2I communications
  - Physical layer：OFDM/OFDMA

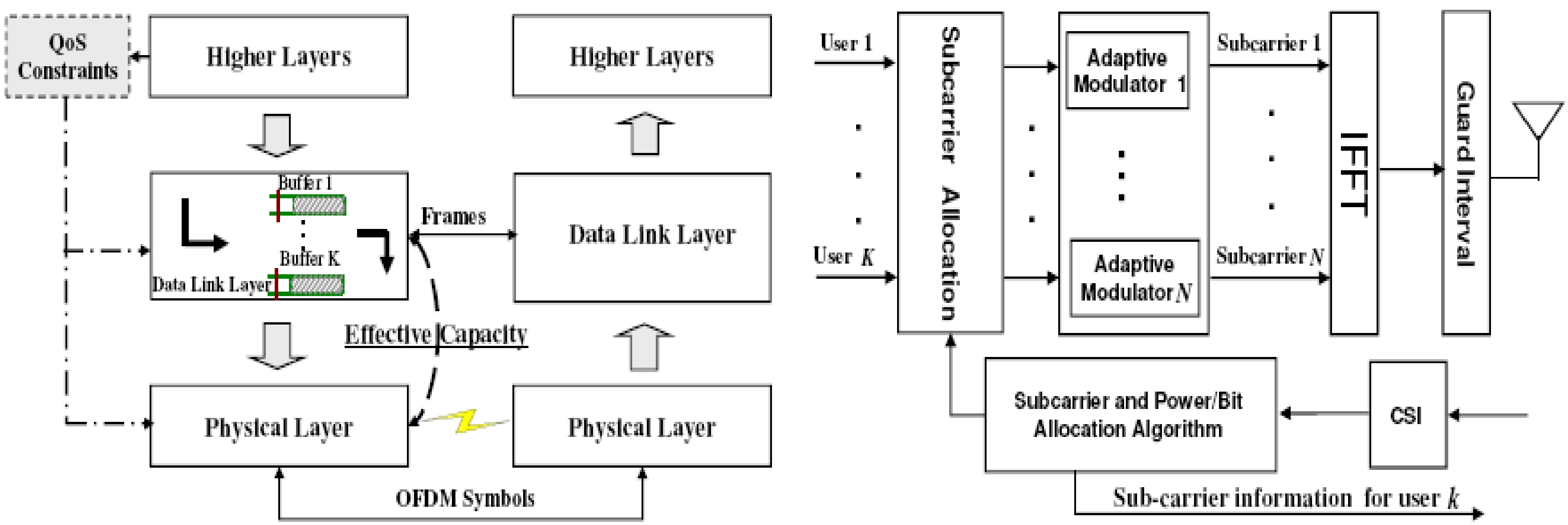


- Resource allocation
  - allocate sub-carriers to minimize the total power consumption while still satisfying the given delay aware QoS constraints of specified application.

* "Quality-of-Service Driven Power, Bit and Subcarrier Allocation Policy for Vehicular Communication Networks", accepted by *IEEE Journal on Selected Areas in Communications (JSAC)*

CLD in Vehicular Communication Networks

- Cross-layer framework



(a) (b)

CLD in Vehicular Communication Networks

- Problem formulation
  - The resource allocation is formulated as a constrained optimization problem
  - **Optimization objective: minimizing the transmit power of basestation**
  - **Constraints**
    - QoS requirements; Subcarrier

0-1 integer programming problem

$$\min_{\Omega_k, C_{k,n}} \sum_{k=1}^{K} \sum_{n \in \Omega_k} \mathrm{E}\left[\frac{1}{\alpha_{k,n}}\left(2^{C_{k,n}} - 1\right)\right],$$

$$\text{s.t.} \quad -\frac{1}{\theta_k}\log\left(\mathrm{E}\left[e^{-\theta_k T_f B_N \sum_{n\in\Omega_k} C_{k,n}}\right]\right) \geq E_c^k, \forall k,$$

$$C_{k,n} \geq 0, \forall k, n,$$

$$\Omega_1 \cup \Omega_2 \cup \ldots \cup \Omega_K \subseteq \{1, 2, \ldots, N\},$$

$$\Omega_i \cap \Omega_j = \varnothing, \quad i \neq j.$$

CLD in Vehicular Communication Networks

- Time-sharing
  - Time-sharing: release the integer variable
  - With two new variables the problem is converted into a convex optimization problem

$$\arg\min_{\rho_{k,n},R_{k,n}} \sum_{k=1}^{K}\sum_{n=1}^{N} \mathrm{E}\left\{\frac{\rho_{k,n}}{\alpha_{k,n}}\left(2^{\frac{R_{k,n}}{\rho_{k,n}}}-1\right)\right\},$$

$$\text{s.t.} \quad \mathrm{E}\left\{e^{-\theta_k \frac{T_f B}{N}\sum_{n\in\Omega_k} C_{k,n}}\right\} \le e^{-\theta_k E_c^k},$$

$$\sum_{\mathrm{k}=1}^{\mathrm{K}} \rho_{\mathrm{k,n}} = 1, \forall n,$$

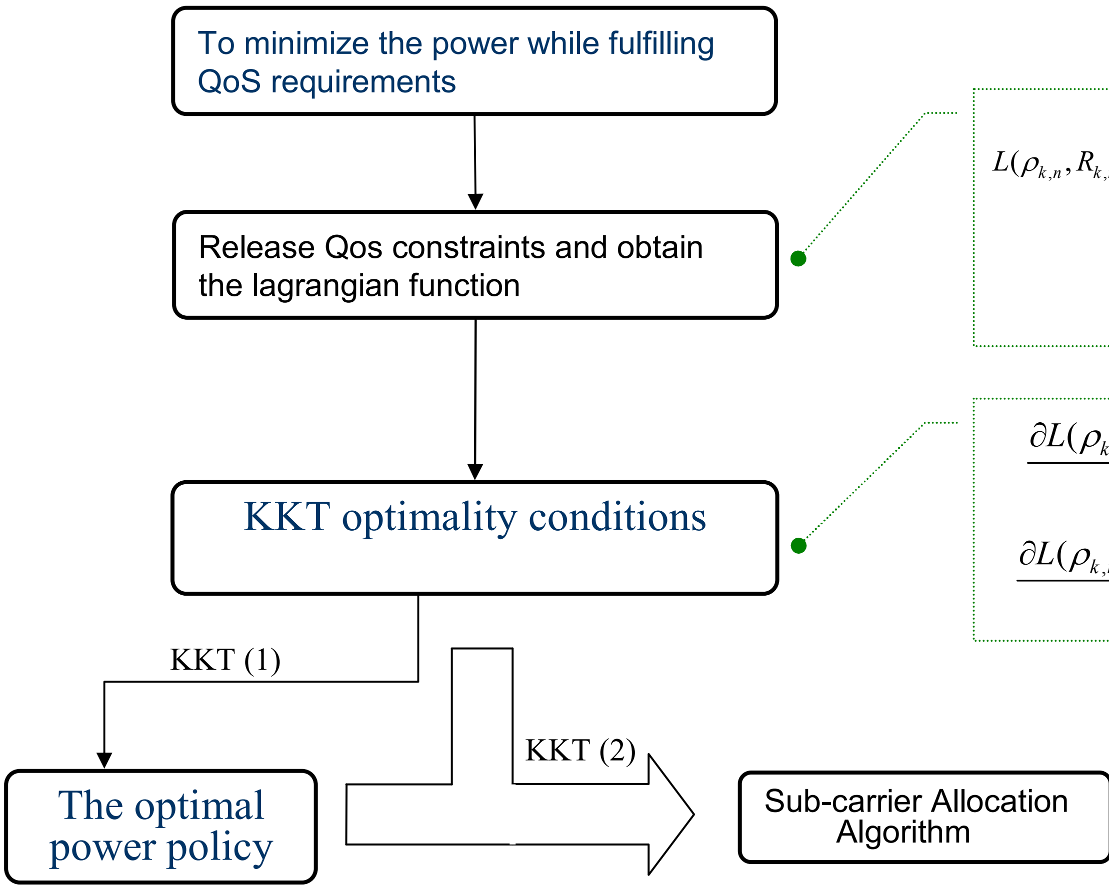
$$R_{k,n} \ge 0, \forall k, n,$$

$$0 \le \rho_{k,n} \le 1, \forall k, n.$$

Time-sharing:

- Time sharing factor $\rho_{k,n}$
- $R_{k,n} = \rho_{k,n} C_{k,n}$

CLD in Vehicular Communication Networks

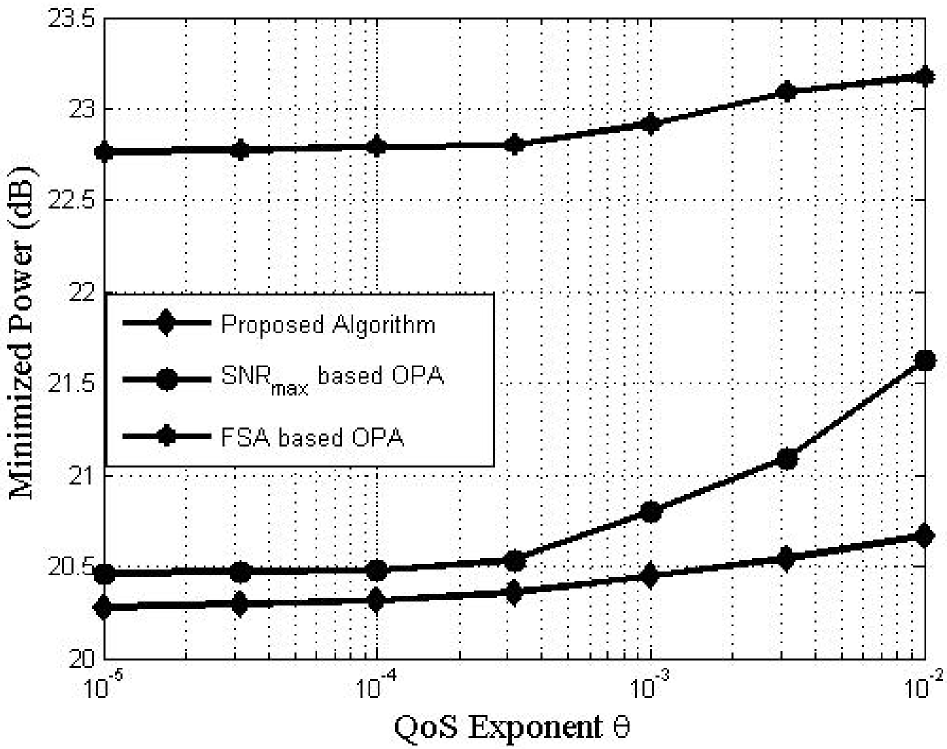


$$L(\rho_{k,n}, R_{k,n}, \lambda_k, \mu_n, \xi_{k,n}) = \sum_{k=1}^{K}\sum_{n=1}^{N} E\left\{\frac{\rho_{k,n}}{\alpha_{k,n}}\left(2^{\frac{R_{k,n}}{\rho_{k,n}}}-1\right)\right\} - \sum_{n=1}^{N}\mu_n\left(\sum_{k=1}^{K}\rho_{k,n}-1\right)$$
$$+\sum_{k=1}^{K}\lambda_k\left(E\left\{e^{-\theta_k\frac{T_f B}{N}\sum_{n\in\Omega_k}C_{k,n}}\right\} - e^{-\theta_k E_c^k}\right) - \sum_{k=1}^{K}\sum_{n=1}^{N}\xi_{k,n}R_{k,n},$$

$$\frac{\partial L(\rho_{k,n}, R_{k,n}, \lambda_k, \mu_n, \xi_{k,n})}{\partial R_{k,n}^*} = 0. \qquad (1)$$

$$\frac{\partial L(\rho_{k,n}, R_{k,n}, \lambda_k, \mu_n, \xi_{k,n})}{\partial \rho_{k,n}^*} \begin{cases} = 0, & \text{if } \rho_{k,n}^* \in (0,1) \\ < 0, & \text{if } \rho_{k,n}^* = 1 \end{cases}. \qquad (2)$$

CLD in Vehicular Communication Networks

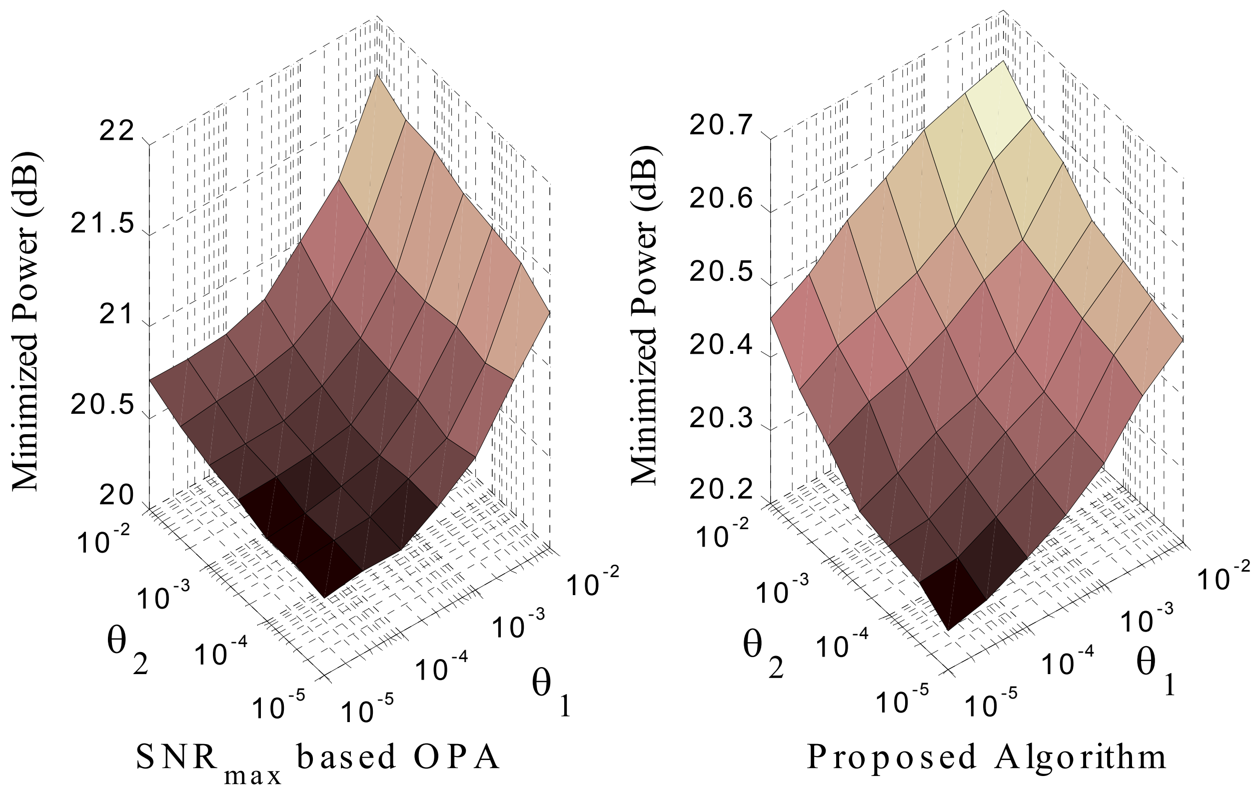


- Subcarrier $N = 32$, user $K = 2$
- Subcarrier bandwidth

  $B_N = 10$ kHz, $T_f = 2$ ms

- Minimized power versus the delay QoS exponentt
- The performance gain in power efficiency increases with the QoS exponent

CLD in Vehicular Communication Networks

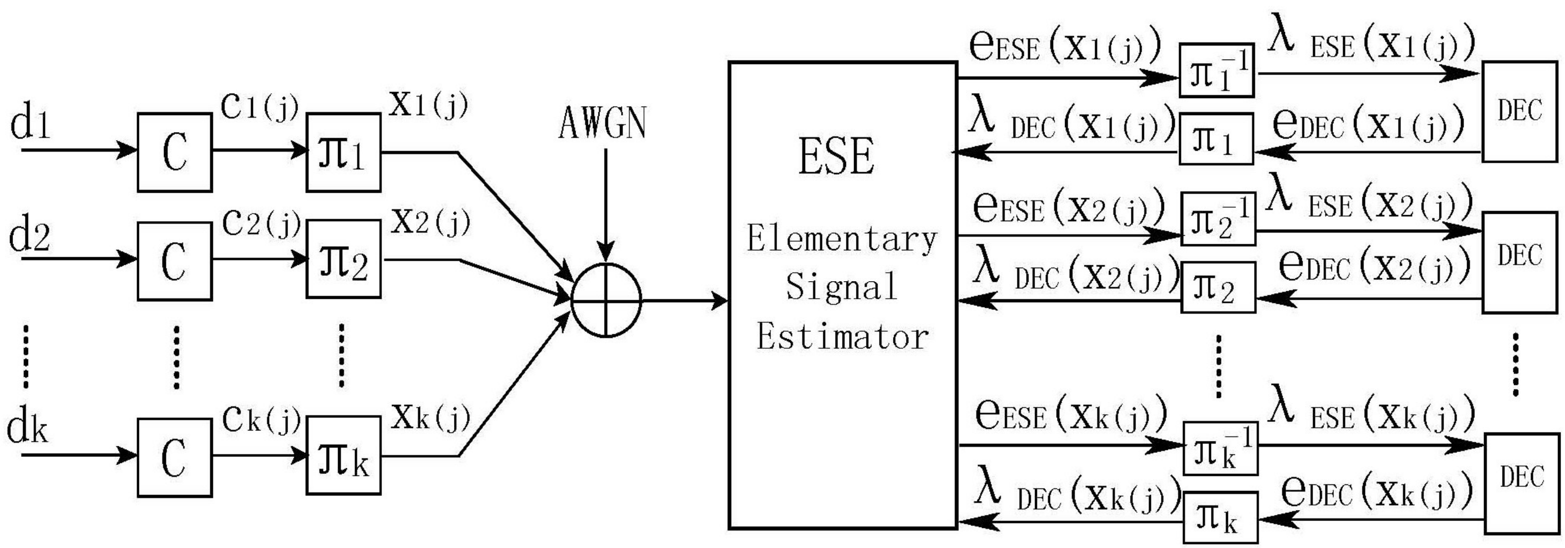


- The performance gain in power efficiency increases with the QoS exponent

Contents

Concept of IDMA

- Interleave Division Multiple Access
  - Interleaver is the mean to distinguish different user
  - Low cost detection based on Gaussian approximation
  - SCM & High spectral/power efficiency



Concept of IDMA

- Gaussian Approximated Detection

Gaussian Approximation

- $$r(j)=\sum_{k=1}^{K}h_k x_k(j)+n=h_k x_k(j)+\zeta_k(j)$$

- Estimate: $$e_{ESE}(j)=2h_k\cdot\frac{r(j)-E(\zeta_k(j))}{Var(\zeta_k(j))}$$

- Decode: $$e_{DEC}(x(j))=C^{-1}(\lambda_{ESE}(x(j)))-\lambda_{ESE}(x(j))$$

IDMA in Cognitive Radio*

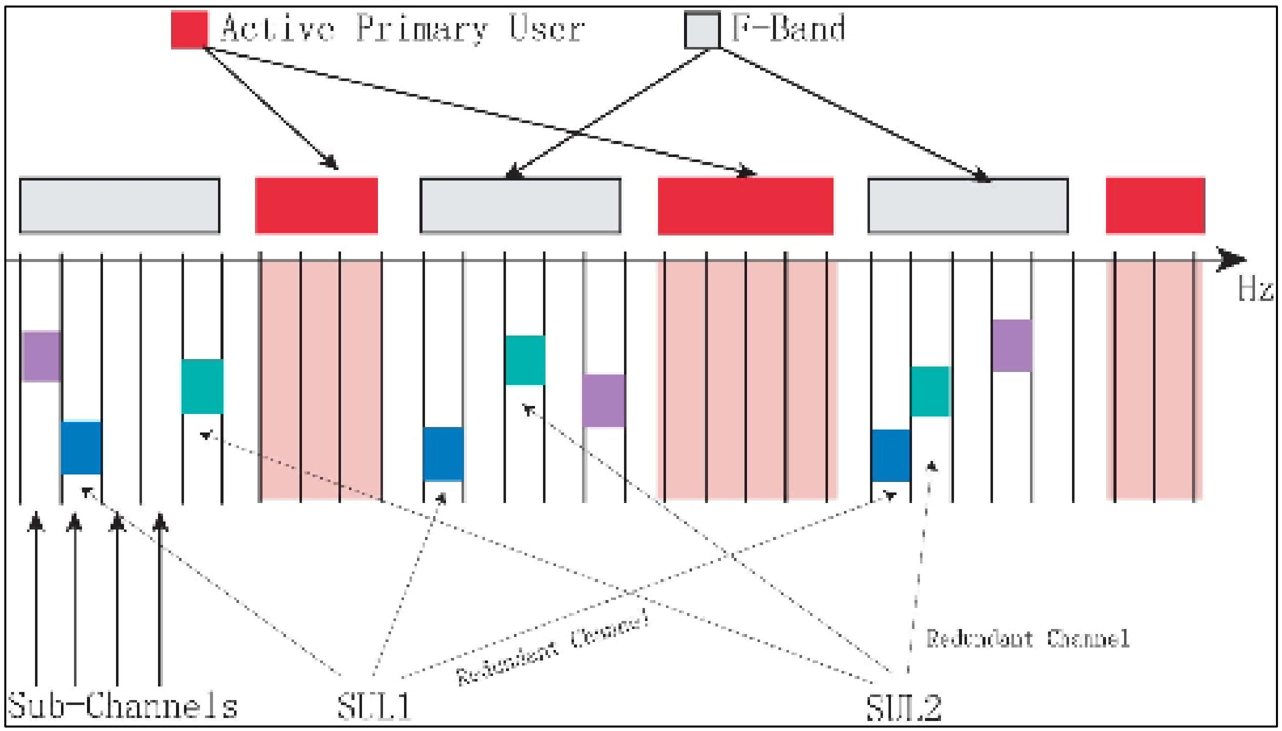
- Cognitive Radio Scenario
  - Overlay
  - Underlay:
    - Primary User (PU) and Secondary User (SU) cannot coexist on the same frequency
- Challenges
  - There exists certain interference period due to the delay of sensing
  - SU link is easily interrupted by the re-appearance of PU

* "A Novel IDM-CORVUS Model in Cognitive Radio", *proc. of IEEE International Symposium on Communication and Information Technology (ISCIT), Sep.28-30 2009*

IDMA in Cognitive Radio

❑ CORVUS Model

- ➢ Sub-channel of one SU link should be scattered among different F-bands
- ➢ Save redundant sub-channels to keep the maintenance of SU link



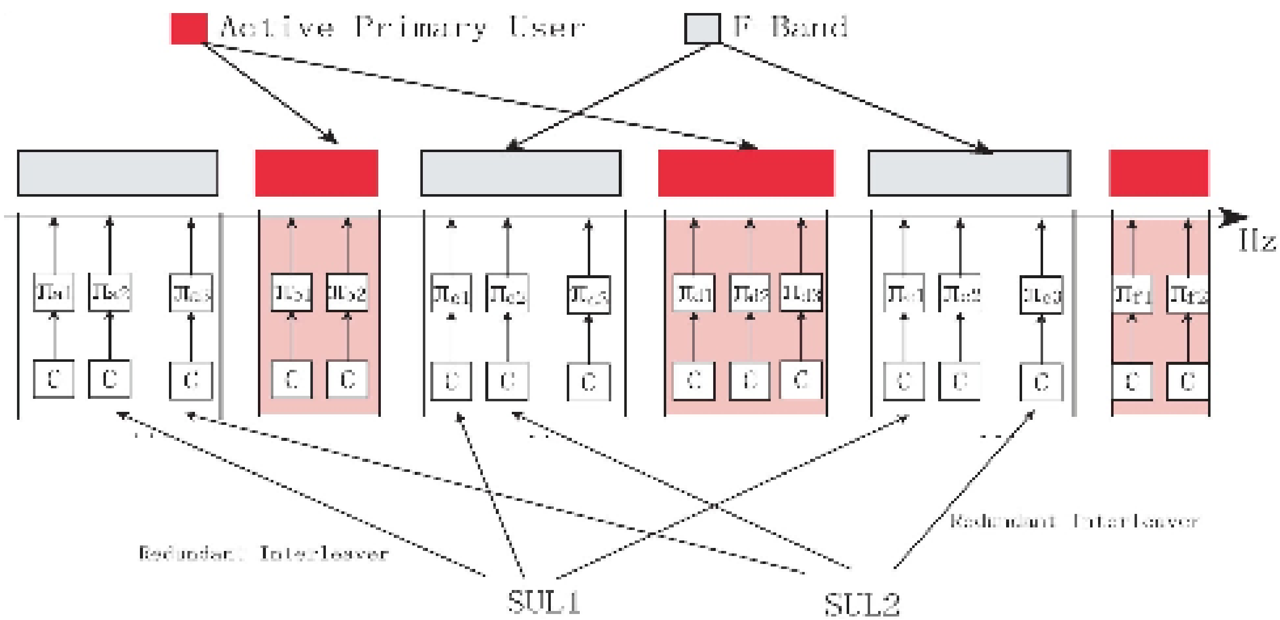
IDMA in Cognitive Radio

- Drawbacks of CORVUS
  - Heavily loaded scenario: no longer effective to alleviate the mutual interference
  - Spectrum waste: Reserving redundant sub-channels
  - The Narrow bandwidth of sub-channels

Orthogonal MA Scheme → Non-orthogonal MA Scheme

IDMA in Cognitive Radio

- IDM-CORVUS
  - Broadband property of IDMA: the secondary user enjoys the whole bandwidth of these F-bands
  - Reserving redundant interleavers: keep the SUL maintenance during PU reappearance without introducing the spectrum waste



IDMA in Cognitive Radio

- SU link:
  - Each SU is equipped with L interleavers, where L is the number of available F-bands.

$$x_k(j) = \sum_{l=1}^{L-L_{red}} x_l(j) \cdot \exp(i\theta_l)$$

L_{red} : the number of redundant interleavers.

$\exp(i\theta_l)$: modulation factor due to the l-th F-band

IDMA in Cognitive Radio

- Tradeoff between Reliability and Throughput

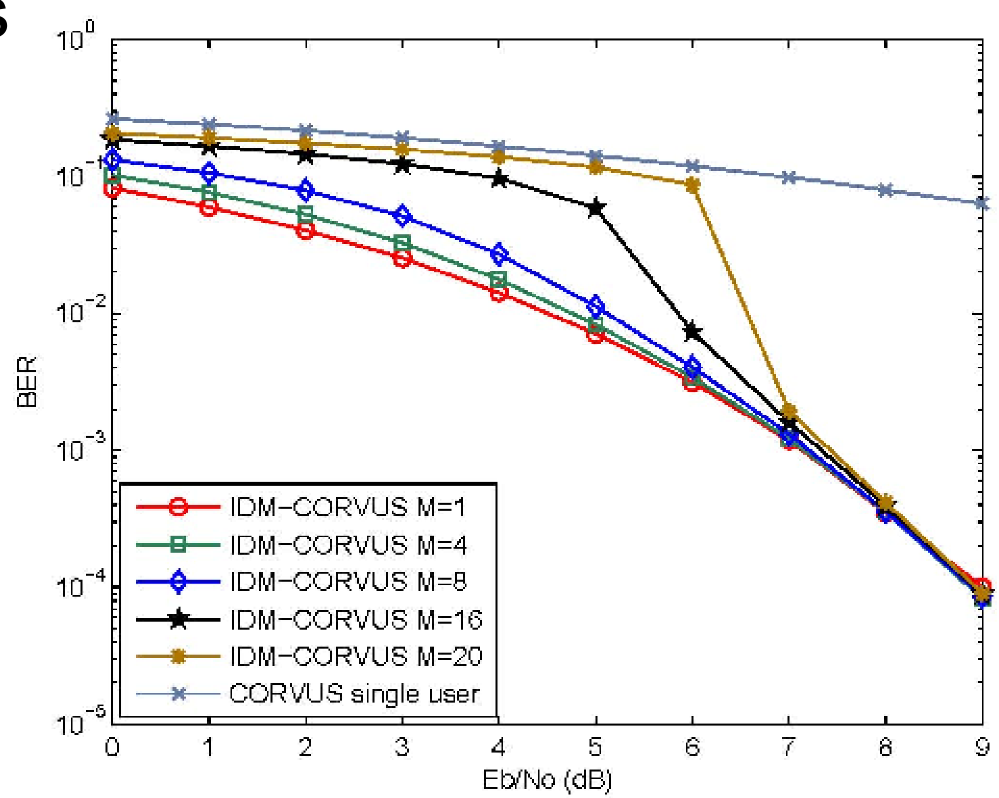
$$x_k(j)=\sum_{m=1}^{\alpha(L-L_{red})} x_m(j)\cdot\exp(i\theta_m)+\sum_{n=\alpha(L-L_{red})+1}^{L-L_{red}} x_n(j)\cdot\exp(i\theta_n)$$

- α : Multiplexing factor
- Reliability: Sending same data stream through M layers
- Throughput: Sending different data through N layers

IDMA in Cognitive Radio

❑ Simulation Results

- Rate of repetition code=1/32
- Iteration number 15
- Equal power allocation
- 3 interleavers per user
- 1 redundant interleaver per user



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  - IDMA in Cognitive Radio Network
- Other Related Work

Other Related Works

- Books:
  - "Cross Layer Design: From Theory to Application" (Chinese Version), published by posts & Telecom Press.
- Papers:
  - Game theoretic CLD in Multi-media Sensor Network
    - "Optimal and Fair Resource Allocation for Multiuser Wireless Multimedia Transmissions," *EURASIP Journal on Wireless Communications and Networking*, 2009.
    - "Co-opetition Strategy for Collaborative Multiuser Multimedia Resource Allocation," *EEE ICC2009, Dresden, Germany, June 2009*.
    - "Novel Coopetition Paradigm Based on Bargaining Theory for Collaborative Multimedia Resource Management," *IEEE PIMRC 2008，Cannes，France*
    - "A Cross-Layer Transmission Scheduling Scheme for Wireless Sensor Networks", *Computer Communications, 21 June 2007*

Other Related Work

- **Papers:**
  - CLD in Cognitive Radio
    - "Co-opetition Strategy Based on Kalai-Smorodinsky Bargaining Solution for Spectrum Sharing in Multicarrier Cognitive Radio Systems ," *submitted to IEEE Trans. on Vehicular Technology*
  - IDMA in Cooperative Network
    - "A Multi-source Cooperative Scheme based on IDMA aided Superposition Modulation", *submitted*
  - IDMA in Common Frequency Network
    - Inter-cell interference cancellation

Thanks
For Your Attention!

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