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Cross-layer resource allocation in wireless multi-hop networks with outdated channel state information

Key words: Wireless multi-hop networks, Outdated channel state information, Cross-layer resource allocation, Distributed algorithm

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Motivation

- To achieve optimal resource allocation, the cross-layer resource allocation problem in wireless multi-hop networks has been extensively studied in the past few years.

- Disadvantages of existing methods:

  The existing cross-layer designs depend on the following two assumptions:

  - the network is static;

  - nodes have real-time and perfect channel state information (CSI) knowledge for resource allocation.

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Innovation

(1) A closed-form expression of conditional average capacity under the signal-to-interference-plus-noise ratio (SINR) model is derived by considering the probability distribution function of current CSI conditioned on outdated CSI.

(2) The impact of outdated CSI on cross-layer resource allocation is firstly considered in dynamic multi-hop wireless networks and a framework with outdated CSI is proposed to jointly optimize congestion control in the transport layer, channel allocation in the data link layer, and power control in the physical layer.

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Design method

The signal received by node *n* can be written as follows:

$$y_n = h_{mn} x_m + w_n$$

According to the general correlation model, the actual CSI accounting for the CSI outdatedness is modeled as

$$h_{mn} = \rho \bar{h}_{mn} + \sqrt{1-\rho^2}\, e_{mn}$$

where $\bar{h}_{mn}$ denotes the outdated channel response, e_{mn} is a complex Gaussian random variable with zero mean and unit variance, uncorrelated with $\bar{h}_{mn}$, and ρ is the time correlation coefficient defined as

$$\rho = J_0(2\pi f_\mathrm{d} \tau)$$

where f_d represents the Doppler frequency, τ is the delay in time units, and $J_0(\bullet)$ denotes the zero-order Bessel function of the first kind.

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Design method

The probability density function (pdf) of h_{mn} conditioned on $\bar{h}_{mn}$ can be easily obtained by applying Bayes' theorem:

$$h_{mn} \mid \bar{h}_{mn} \sim CN(\rho \bar{h}_{mn}, 1-\rho^2)$$

Let $\gamma_{mn} = \left|\boldsymbol{h}_{mn}\right|^2 / \sigma_w^2$ denote the instantaneous channel-to-noise ratio (CNR) of the link (*m*, *n*) in a given time slot and $\bar{\gamma}_{mn} = \left|\bar{\boldsymbol{h}}_{mn}\right|^2 / \sigma_w^2$ be the corresponding outdated value. γ_{mn} conditioned on $\bar{\gamma}_{mn}$ follows a non-central chi-square distribution with two degrees of freedom.

The expectation of conditional capacity of link *l* can be described as follows:

$$\hat{C}_{l,\gamma|\hat{\gamma}}(P) = E_{\gamma|\hat{\gamma}}\left\{B\log_2\left(1+K\frac{P_l\gamma_{ll}}{\sum_{i\neq l}P_i\gamma_{il}+1}\right)\right\}, \quad \forall i \neq l, \forall l \in L$$

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Design method

The network utility maximization (NUM) problem can be stated as follows:

$$\underset{F,X,P}{\text{maxmize}} \quad \sum_{s\in S} U(f_s)$$

$$\text{subject to}$$

$$\boldsymbol{x}_l 1^{\mathrm{T}} = 1, \forall l \in L,$$

$$\boldsymbol{x}_l = \boldsymbol{x}_i, \forall l, i \in L_n^k, n \in N, k \in I_n,$$

$$0 \le \sum_{m\in N_n^{\text{out}}} P_{nm} \le P_n^{\max},$$

$$\sum_{s:l\in L(s)} f_s \le \hat{C}_{l,\gamma|\hat{\gamma}}(\boldsymbol{X},\boldsymbol{P}), \forall l \in L,$$

$$\hat{C}_{l,\gamma|\hat{\gamma}}(\boldsymbol{X},\boldsymbol{P}) = E_{\gamma|\hat{\gamma}}\left\{B\log_2\left(1+K\frac{P_l\gamma_{ll}}{\sum_{i\neq l} x_i x_l^T P_i \gamma_{il}+1}\right)\right\}, \ \forall i \neq l, \forall l \in L.$$

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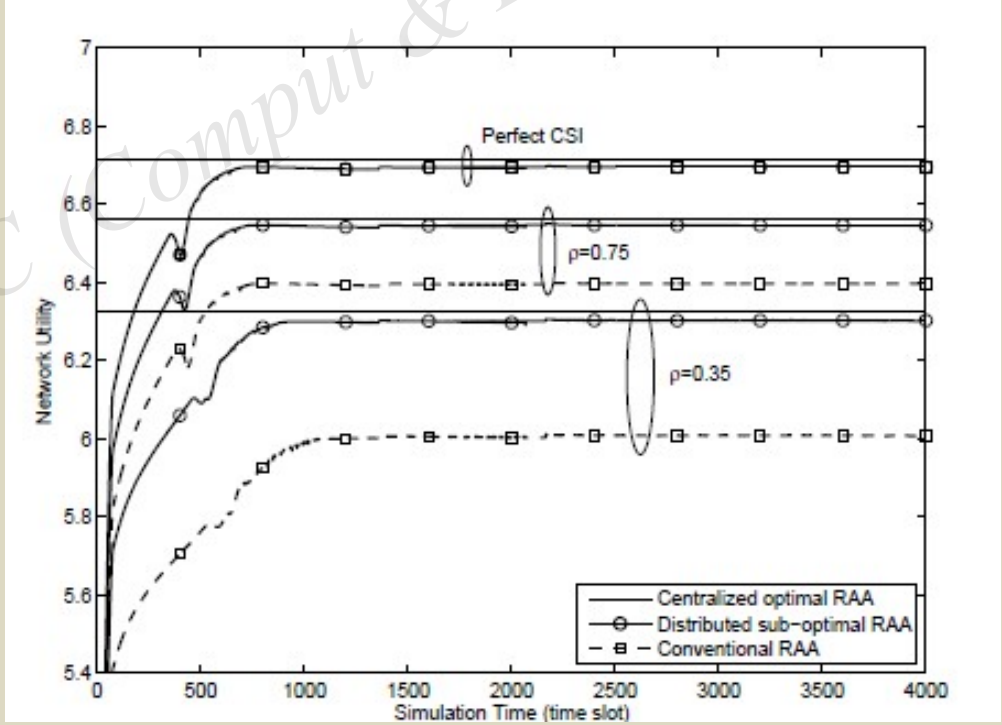
Results

(1) The expectation of conditional capacity under the SINR model can be derived as

$$\widehat{C}_{l,\gamma|\hat{\gamma}}(X,P)=\frac{B}{\log 2}\left[\tau_l-\tau_{1'}\beta_l+\tau_{2'}\beta_l(\beta_{1'}-1)-\tau_{3'}\beta_l(\beta_{1'}-1)(\beta_{2'}-1)+\ldots\right.$$

$$\left.+(-1)^m\tau_{m'}\beta_l(\beta_{1'}-1)(\beta_{2'}-1)\ldots(\beta_{(m-1)'}-1)+(-1)^{m+1}\beta_l(\beta_{1'}-1)(\beta_{2'}-1)\ldots(\beta_{m'}-1)+\beta_l\ln K\right]$$

(2) Simulation results for the proposed algorithm:



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Conclusions

In this paper, we have studied the problem of resource allocation in wireless multi-hop networks with outdated channel sensing under channel conditions where there is correlation between the outdated CSI and current CSI.

- The closed-form expression of the expectation of conditional capacity is obtained.
- Both a centralized optimal and a distributed sub-optimal joint power, channel, and rate allocation algorithm are proposed in wireless multi-hop networks with outdated CSI.
- Simulation results show that the proposed resource allocation algorithm can allocate the resource reasonably and achieve significantly higher network utility than the conventional one.

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