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Cross-layer resource allocation in wireless multi-hop networks with outdated channel state information

Key words: Wireless multi-hop networks, Outdated channel state information, Cross-layer resource allocation, Distributed algorithm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

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ratio (SINR) model is derived by considering the probability distribution function of current CSI conditioned on outdated CSI.

(2) The impact of outdated CSI on cross-layer resource allocation is firstly considered in dynamic multi-hop wireless networks and a framework with outdated CSI is proposed to jointly optimize congestion control in the transport layer, channel allocation in the data link layer, and power control in the physical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

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where $\bar{h}_{mn}$ denotes the outdated channel response, e_{mn} is a complex Gaussian random variable with zero mean and unit variance, uncorrelated with $\bar{h}_{mn}$, and ρ is the time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

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 $\gamma_{mn} = |\boldsymbol{h}_{mn}|^2 / \boldsymbol{\sigma}_w^2$ denote the instantaneous channel-to-noise ratio (CNR) of the link (*m, n*) in a given time slot and $\bar{\gamma}_{mn} = |\bar{\boldsymbol{h}}_{mn}|^2 / \boldsymbol{\sigma}_w^2$ 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:

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

Design method

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

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

$$\text{subject to}$$

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

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

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

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

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

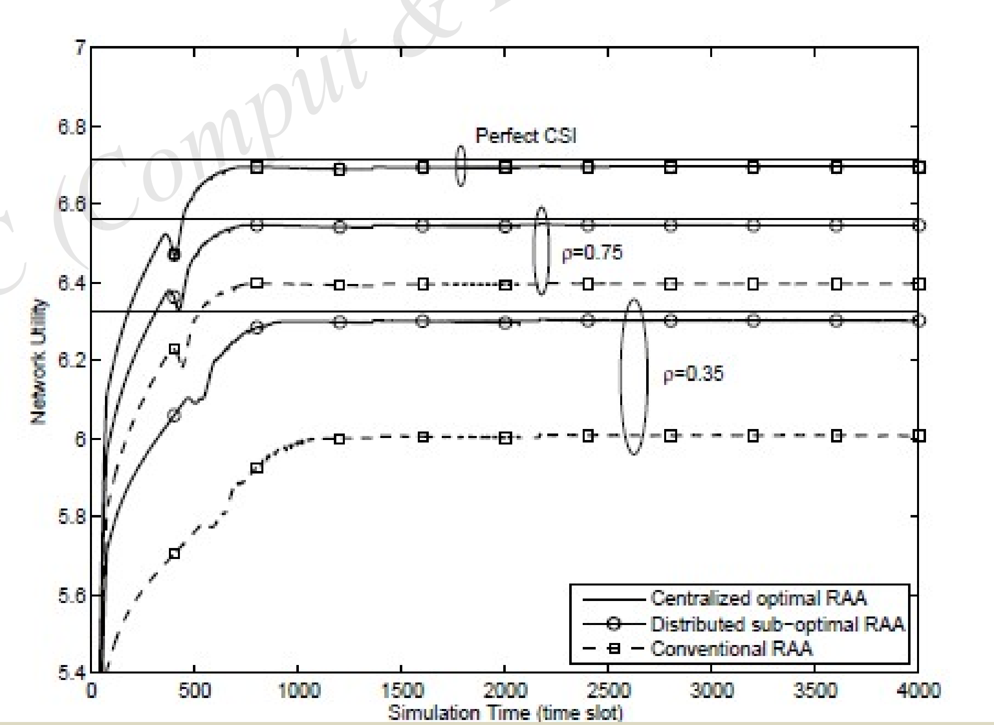
Results

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

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

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

(2) Simulation results for the proposed algorithm:



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.