Inter Cell Interference Management and Intra Cell User Scheduling in Multi Cell Networks

Arunakumari Bellamkonda\(^1\), R. Rammohan Rao\(^2\)

\(^1\)Pursuing M.Tech(CSE), Nalanda Institute of Engineering & Technology, Siddharth Nagar, Sattenapalli, Guntur., Affiliated to JNTUK, Kakinada, A.P., India.

\(^2\)Asst.Professor, Department of Computer Science Engineering, Nalanda Institute of Engineering & Technology, Siddharth Nagar, Sattenapalli, Guntur., Affiliated to JNTUK, Kakinada, A.P., India.

kondaveetiaruna@gmail.com

Abstract - To achieve high spatial capacity, wireless cellular networks consider the dense deployment of base stations (BSs) that cover small cells. As a consequence, inter-cell interference (ICI) from neighboring BSs becomes a major source of performance degradation and the portion of users whose capacity is naturally limited by ICI grows. In order to fully attain the potential gain of multi-cell networks, the coordination of transmissions among BSs which can effectively manage ICI is essential. In this paper, we propose a distributive queue-aware intra-cell user scheduling and inter-cell interference (ICI) management control design for a delay-optimal cellular downlink system with M base stations (BSs), and K users in each cell. Each BS has K downlink queues for K users respectively with heterogeneous arrivals and delay requirements. The ICI management control is adaptive to joint queue state information (QSI) over a slow time scale, while the user scheduling control is adaptive to both the joint QSI and the joint channel state information (CSI) over a faster time scale.

Keywords - Multi-cell Networks, Inter cell Interference (ICI) Management, Intra cell user scheduling.

1. Introduction

It is well-known that cellular systems are interference limited and there are a lot of works to handle the inter-cell interference (ICI) in cellular systems. Specifically, the optimal binary power control (BPC) for the sum rate maximization has been studied in [1]. They showed that BPC could provide reasonable performance compared with the multi-level power control in the multi-link system. In [2], the authors studied a joint adaptive multi-pattern reuse and intra-cell user scheduling scheme, to maximize the long-term network-wide utility. The ICI management runs at a slower scale than the user selection strategy to reduce the communication overhead. In [3] and the reference therein, cooperation or coordination is also shown to be a useful tool to manage ICI and improve the performance of the cellular network.

However, all of these works have assumed that there are infinite backlogs at the transmitter, and the control policy is only a function of channel state information (CSI). In practice, applications are delay sensitive, and it is critical to optimize the delay performance in the cellular network. A systematic approach in dealing with delay-optimal resource control in general delay regime is via Markov Decision Process (MDP) technique. In [4], [5], the authors applied it to obtain the delay-optimal cross-layer control policy for broadcast channel and point-to-point link respectively. However, there are very limited works that studied the delay optimal control problem in the cellular network. Most existing works simply proposed heuristic control schemes with partial consideration of the queuing delay [6]. As we shall illustrate, there are various technical challenges involved regarding delay-optimal cellular network.

- **Curse of Dimensionality:** Although MDP technique is the systematic approach to solve the delay-optimal control problem, a primal...
difficulty is the curse of dimensionality [7]. For example, a huge state space (exponential in the number of users and number of cells) will be involved in the MDP and brute force value or policy iterations cannot lead to any implementable solution [8], [9]. Furthermore, brute force solutions require explicit knowledge of transition probability of system states, which is difficult to obtain in the complex systems.

- **Complexity of the Interference Management**: Jointly optimal ICI management and user scheduling requires heavy computation overhead even for the throughput optimization problem [2]. Although grouping clusters of cells [1] and considering only neighboring BSs [10] were proposed to reduce the complexity, complex operations on a slot by slot basis are still required, which is not suitable for the practical implementation.

- **Decentralized Solution**: For delay-optimal multi-cell control, the entire system state is characterized by the global CSI (CSI from any BS to any MS) and the global QSI (queue length of all users). Such system state information are distributed locally at each BS and centralized solution (which requires global knowledge of the CSI and QSI) will induce substantial signaling overhead between the BSs and the Base Station Controller (BSC).

In this paper, we propose a distributive queue-aware intra-cell user scheduling and inter-cell interference (ICI) management control design for a delay-optimal cellular downlink system with M base stations (BSs), and K users in each cell. Each BS has K downlink queues for K users respectively with heterogeneous arrivals and delay requirements. The ICI management control is adaptive to joint queue state information (QSI) over a slow time scale, while the user scheduling control is adaptive to both the joint QSI and the joint channel state information (CSI) over a faster time scale.

2. ICI Management and User Scheduling Control Policy

To achieve high spatial capacity, wireless cellular networks consider the dense deployment of base stations (BSs) that cover small cells. As a consequence, inter-cell interference (ICI) from neighboring BSs becomes a major source of performance degradation and the portion of users whose capacity is naturally limited by ICI grows. In order to fully attain the potential gain of multi-cell networks, the coordination of transmissions among BSs which can effectively manage ICI is essential. The key intuition of BS coordination is that the achievable rates, which depend on the amount of ICI, can be increased by turning off some of neighboring BSs. Thus there are cases when the increment of achievable rates preponderates the sacrifice of taking away transmission opportunities at the neighboring BSs. In particular, this usually happens to users at cell edges severely suffering from the ICI since the increment of achievable rates may be sufficiently large.

For implementation consideration, the ICI management control is computed at the BSC at a longer time scale and it is adaptive to the QSI only. On the other hand, the intra-cell user scheduling control is computed distributively at the BS at a smaller time scale and hence, it is adaptive to both the CSI and QSI. At the beginning of the slot, the BSC will decide which BSs are allowed to transmit according to a stationary ICI management control policy defined below.

**Definition 1 (Stationary ICI Management Control Policy)**:
A stationary ICI management control policy \( \Omega_p : Q \rightarrow P \) is defined as the mapping from current global QSI to an ICI management pattern \( \Omega_p(Q) = p \).

Let \( \chi(t) = \{H(t),Q(t)\} \) to be the global system state at the beginning of slot t. The active user at each cell is selected according to a user scheduling policy defined below.

**Definition 2 (Stationary User Scheduling Policy)**:
A stationary user scheduling policy \( \Omega_s : \{Q,H\} \rightarrow S \) is defined as the mapping from current global system state to current user scheduling action \( \Omega_s(X) = s \in S \). The scheduling action \( s \) is a set of all the users’ scheduling indicator variable, i.e., \( s = \{s(m,k), \text{for all } k \in Km, \text{for all } m\} \). It represents which users are scheduled and which users are not in any given slot. \( S \) is the set of all user scheduling actions.

3. Delay Optimal Multi Cell Control Problem

For delay-optimal multi-cell control, the entire system state is characterized by the global CSI (CSI from any BS to any MS) and the global QSI (queue length of all users). Such system state information are distributed locally at each BS and centralized solution
(which requires global knowledge of the CSI and QSI) will induce substantial signaling overhead between the BSs and the Base Station Controller (BSC). Due to the two time-scale control structure, the delay optimal control is formulated as an infinite-horizon average cost Partially Observed Markov Decision Process (POMDP). Exploiting the special structure, we propose an equivalent Bellman Equation to solve the POMDP.

For some positive constants $\beta = \{ \beta_{m,k} \}$, for all $k \in K_m$, for all $m$, finding a stationary control policy $\Omega$ that minimizes:

$$\min_{\Omega} J_{\beta}^{\Omega} = \sum_{(m,k)} \beta_{m,k} T_{m,k}^{\ast}(\Omega)$$

$$= \lim_{T \to \infty} \sup_{\Omega} \frac{1}{T} \sum_{t=1}^{T} E_{\Omega}^{X}(g(X(t),\Omega(X(t))))$$

where $g(X(t), \Omega(X(t)) = \sum m,k \beta_{m,k} f(Q(m,k))$ is the per-slot cost, and $E$ denotes the expectation w.r.t. the induced measure (induced by the control policy $\Omega$ and the transition kernel in (4)). The positive constants $\beta$ indicate the relative importance of the users and for a given $\beta$, the solution to (6) corresponds to a Pareto optimal point of the multi-objective optimization problem given by $\min T_{m,k}^{\ast}(\Omega)$, for all $m, k$.

4. Solution to Delay Optimal Multi Cell Control Problem

In this section, we will show that the delay optimal problem can be modeled as an infinite horizon average cost POMDP, which is a very difficult problem. By exploiting the special structure, we shall derive an equivalent Bellman equation to solve the POMDP problem. For instance, in the delay optimal problem, the ICI management control policy $\Omega_p$ is adaptive to the QSI $Q$, while the user scheduling policy $\Omega_s$ is adaptive to the complete system state $\{Q,H\}$. Therefore, the optimal control policy $\Omega$ cannot be obtained by solving a standard Bellman equation from conventional MDP. In fact, problem is a POMDP with the following specification.

- **State Space**: The system state is the global QSI and CSI $X = \{Q,H\}$.
- **Action Space**: The action is ICI management pattern and user scheduling $(p, s) \in \{P, S\}$.
- **Transition Kernel**: The transition probability $Pr\{X|X, p, s\}$.
- **Per-Slot Cost Function**: The per-slot cost function is $g(X, p, s) = \sum m,k \beta_{m,k} f(Q(m,k))$.
- **Observation**: The observation for ICI management control policy is global QSI, i.e., $z_p = Q$, while the observation for User scheduling policy is the complete system state, i.e., $z_s = X$.
- **Observation Function**: The observation function for ICI management control policy is $Os(z_p, X, p, s) = 1$, if $z_p = Q$, otherwise 0. Furthermore the observation function for user scheduling policy is $Os(z_s, X, p, s) = 1$, if $z_s = X$, otherwise 0.

While POMDP is a very difficult problem in general, we shall utilize the notion of action partitioning in our problem to substantially simplify the problem. We first define partitioned actions below.

**Definition 3 (Partitioned Actions)**

Given a control policy $\Omega$, we define $\Omega(Q) = \{(p, s) = (\omega, \Omega(Q)) : X = (Q,H) \}$ is the collection of actions under a given $Q$ for all $H \in H$. The complete policy is therefore equal to the union of all partitioned actions, i.e., $\Omega = \bigcup Q \Omega(Q)$.

Based on the action partitioning, we can transform the POMDP problem into a regular infinite-horizon average cost MDP. Furthermore, the optimal control policy $\Omega^*$ can be obtained by solving an equivalent Bellman equation which is summarized in the theorem below.

**Theorem 1 (Equivalent Bellman Equation)**: The optimal control policy $\Omega^* = (\omega^*, \Omega^*_{Q})$ in delay optimal multi cell control problem can be obtained by solving the equivalent Bellman equation given by:

$$V(Q) + \theta = \min_{\Omega(Q)} [g(Q, \Omega(Q)) + \sum_{Q} pr\{Q | Q, \Omega(Q)\} V(Q^i)]$$

Where $g(Q, \Omega(Q)) = \sum m,k \beta_{m,k} f(Q(m,k))$ is the per-slot cost function, and the transition kernel is given by $Pr\{Q^i | Q, \Omega(Q)\} = \mathbb{E}_H \{ Pr \{ Q^i | Q, H, \Omega(X) \}\}$.
\[ \Pr \{ Q' | Q, H, \Omega | \chi \} = \begin{cases} \Pr \{ A \} & \text{if } Q' = \left[ (Q - U)^+ + A \right]_{\Lambda^N} \\ 0 & \text{otherwise} \end{cases} \]

Where \( U = \{ U_m \} \), where \( m = 1, 2, \ldots, M \). \( U_m = \{ U(m,k) \} \) where \( k = 1, 2, \ldots, K \) and \( U(m,k) = R(m,k)(X, \Omega(X)) \) for \( k \in K_m \)

5. Conclusion

Achieving sufficient spatial capacity gain by having small cells requires careful treatment of inter-cell interference (ICI) management via BS power coordination coupled with user scheduling inside cells. In this paper, we propose a distributive queue-aware intra-cell user scheduling and inter-cell interference (ICI) management control design for a delay-optimal cellular downlink system with \( M \) base stations (BSs), and \( K \) users in each cell. Each BS has \( K \) downlink queues for \( K \) users respectively with heterogeneous arrivals and delay requirements. The ICI management control is adaptive to joint queue state information (QSI) over a slow time scale, while the user scheduling control is adaptive to both the joint QSI and the joint channel state information (CSI) over a faster time scale.

References


AUTHORS PROFILE

Arunakumari Bellamkonda, Pursuing M.Tech (CS) from Nalanda Institute of Engineering & Technology, Siddharth Nagar, Sattenapalli, Guntur, Affiliated to JNTUK, Kakinada, A.P., India. My research Interests are computer networks, Data Mining.

R. Rammohan Rao, working as Professor & Head, Department of Computer Science Engineering at Nalanda Institute of Engineering & Technology,Siddharth Nagar, Sattenapalli, Guntur Affiliated to JNTUK, Kakinada, A.P., India. My research Interests are Mobile Computing, Network Security and Mobile Networks. He is a Life member of AMIT.