



A COORDINATED, NETWORK-AWARE GUARD CHANNEL SCHEME WITH INTER-CELL COMMUNICATION

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ABSTRACT

The bane of traditional guard channel schemes is its reliance on static allocation which makes it lack broader network awareness. This has resulted to improper utilization of available spectrum and increase in call-dropping rates in unstable traffic conditions. This paper suggests the Coordinated, Network-Aware Guard Channel (CNAGC) scheme. In the methodology, a centralized Network Controller (NC) is integrated with real-time inter-cell communication links. A mathematical model and an optimization algorithm were developed to dynamically adjust guard channel thresholds based on a Global Network State Database, predicted mobility patterns, and neighbouring cell loads. Contrary to conventional strategies, the CNAGC scheme does not prevent neighbouring cells from accepting handoffs when local resources have been used up because it allows base stations to coordinate directly. It was discovered from simulation results that the CNAGC scheme has the best performance when compared with traditional Fixed Guard Channel (FGC) and local Dynamic Guard Channel (DGC) schemes. The handoff dropping probability for CNAGC is 2.5%, compared to 6.8% and 5.5% for FGC and DGC respectively during handoff heavy scenarios. Also, the scheme has the least new call blocking rate of 4.8% and the best channel utilization of 82% compared to 75% utilization of the traditional fixed models. In dense cellular environments, the CNAGC scheme offers a versatile approach for managing resources. The suitability of the scheme for next-generation wireless networks is enhanced by its ability to capitalize on global network intelligence and local inter-cell coordination which brings about optimum spectrum efficiency and a seamless user experience.

Keywords: Guard Channel Scheme, Handoff Management, Inter-Cell Communication, Resource Allocation, Quality of Service (QoS)

INTRODUCTION

Effective techniques for managing resources in cellular networks are needed due to perpetual request for fast and reliable wireless communication. Managing handoffs turns a big issue as mobile users traverse cell boundaries. Calls begin to drop when handoff is not properly handled. This eventually has adverse effect on user experience and network quality of service (QoS). In order to reserve a portion of available channels for handoff calls, guard channel schemes are considered. This helps to prioritize handoffs' admission and eventually reduce their dropping probability. But, inflexible resource assignment adversely affects traditional guard channel schemes. They also lack awareness of the broader network context. This results to improper utilization of available spectrum and unsatisfactory performance (Kanaga and Bamila, 2021). Managing resources in mobile network worsens due to the advent of dense cellular deployments and heterogeneous networks (HetNets). This then underscores the necessity for dynamic and coordinated strategies. In actualizing such coordination, inter-cell communication plays a significant role. It permits base stations to share information about channel availability, traffic load and user mobility patterns (Fauzia *et al.*, 2020). These challenges are what this paper tackles by suggesting the Coordinated, Network-Aware Guard Channel (CNAGC) scheme. The CNAGC scheme flexibly modify guard channel allocations by combining real-time network intelligence and inter-cell communication. This yields efficient resource utilization while sustaining reduced handoff dropping rates.

Literature Review

Guard channel schemes, as a principal strategy for prioritizing handoffs have been elaborately discussed in many literatures. Fixed guard channel allocation is one of the initial strategies where a pre-decided number of channels were earmarked for handoff calls (Ito *et al.*, 2020). These schemes often led to either surplus reservation (leading to new call blocking) or inadequate reservation (leading to handoff dropping), depending on traffic situations, although very easy to execute (Solomon *et al.*, 2019). Dynamic guard channels schemes were suggested in order to mitigate the limitations of fixed allocation. Considering real-time traffic conditions, such as the current number of active handoff calls or the predicted handoff rate, these schemes modify the number of guard channels (Mahmoud *et al.*, 2020). Considering the ratio of handoff attempts to new call attempts, for example, the adaptive guard channel scheme flexibly assigns guard channels (Ojesanmi *et al.*, 2021). Similarly, in predicting traffic patterns and enhancing guard channel allocation, schemes that incorporated fuzzy logic or neural networks have been developed (Yingjie, 2024).

Recent advancements in wireless communication emphasize the importance of network-aware resource management and inter-cell coordination. The concept of software-defined networking (SDN) and network function virtualization (NFV) facilitates centralized control and dynamic resource provisioning, opening new avenues for coordinated guard channel management (Zeina *et al.*, 2025). Studies in 5G and beyond networks highlight the benefits of inter-cell interference coordination (ICIC) and enhanced inter-cell interference coordination (eICIC) in improving overall network performance (Siddiqui *et al.*, 2021). Furthermore,

machine learning techniques are increasingly being applied to predict mobility patterns and optimize resource allocation in a network-aware manner (Liaq et al., 2025). For example, a scheme proposed in (Wang et al., 2021) utilizes deep reinforcement learning to optimize resource allocation across multiple cells, considering handoff requests and new call arrivals. Another relevant work in (Poongod et al., 2021) focuses on a coordinated multi-point (CoMP) transmission and reception scheme to improve handoff performance by sharing channel state information between base stations. The importance of reducing handoff dropping probability through various resource allocation strategies in 5G mmWave networks is emphasized in (Saoud et al., 2025). Selumun et al. 2025 presents a focused review of load balancing strategies within mobile fog networks, emphasizing the fog layer as a critical bridge between edge devices and centralized cloud systems.

A proactive handoff management scheme using mobility prediction for vehicular networks, which inherently involves inter-cell coordination, is discussed in (Yasir et al., 2025). Finally, the concept of a “smart guard channel” that adapts its

size based on the predicted number of handoff requests in dense cellular environments is explored in (Itoro et al., 2020). While existing literature has explored dynamic guard channel allocation and inter-cell coordination separately, a truly integrated and network-aware approach that dynamically adjusts guard channels based on real-time inter-cell communication and network state is still an area with significant potential for improvement. This paper bridges this gap by proposing the CNAGC scheme which leverages a holistic view of the network to achieve optimal performance.

MATERIALS AND METHODS

System Architecture

The proposed Coordinated, Network-Aware Guard Channel (CNAGC) scheme operates within a cellular network environment comprising multiple base stations (BSs) and mobile stations (MSs). The core of the architecture lies in a centralized Network Controller (NC) and a robust inter-cell communication link.

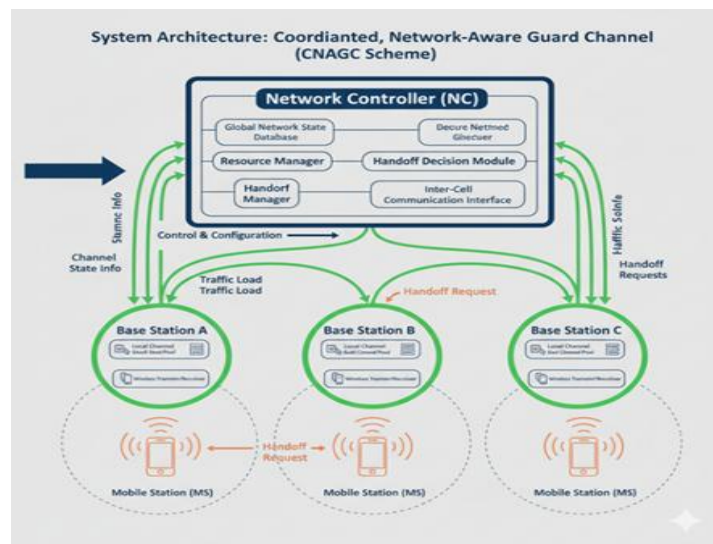


Figure 1: System Architecture

Each Base Station (BS) is responsible for managing its local radio resources, including its total available channels and its allocated guard channels. BSs continuously monitor local traffic load, channel utilization, and active handoff requests. This information, along with channel state information, is periodically transmitted to the Network Controller (NC).

The Network Controller (NC) acts as the central intelligence of the system. It maintains a Global Network State Database, which aggregates real-time information from all connected BSs. The NC comprises several key modules:

- i. **Resource Manager:** This module is responsible for overall channel allocation decisions across the network, considering global network state and traffic demands.
- ii. **Handoff Decision Module:** This module processes handoff requests, determines the optimal target cell and authorizes channel allocation.
- iii. **Inter-cell Communication Interface:** This module facilitates direct communication between neighbouring BSs for rapid information exchange regarding impending handoffs and local channel availability, bypassing the NC for urgent requests.

- iv. **Handoff Manager:** This module oversees the entire handoff process from initiation to completion, ensuring smooth transitions.

The inter-cell communication links allow adjacent BSs to exchange crucial information, such as imminent handoff requests from MSs in their coverage areas and their respective current channel availability, without requiring the NC for every micro-decision. This distributed communication enhances responsiveness, especially for time-sensitive handoff events.

Mathematical Model

The model defines the state of a cellular network and the optimization logic used by the Network Controller (NC) to determine the number of guard channels.

(I) System Variables and Parameters

Let i denote a specific cell in the network.

N_i : Total number of available channels in cell i .

$C_i(t)$: Number of channels currently occupied at time t .

$A_i(t)$: Number of available channels, where

$$A_i(t) = N_i - C_i(t) \quad (1)$$

G_i : The number of guard channels reserved exclusively for handoff calls in cell i .

$\lambda_{n,i}$: Arrival rate of new call requests in cell i (Poisson distributed).

$\lambda_{h,i}$: Arrival rate of handoff requests in cell i (Poisson distributed).

$1/\mu$: Mean channel holding time (exponentially distributed).

S_i : The set of neighbouring cells adjacent to cell i

(2) Call Admission Probabilities

The scheme differentiates between new calls and handoff calls based on the threshold G_i .

New Call Blocking Probability ($P_{b,i}$): A new call is blocked if the number of available channels is less than or equal to the guard channel threshold.

$$P_{b,i} = P(A_i(t) \leq G_i) \quad (2)$$

Handoff Dropping Probability ($P_{d,i}$): In the CNAGC scheme, a handoff is only dropped if the current cell has no channels AND no coordinated neighbouring cell can accept the handoff.

$$P_{d,i} = P(A_i(t) = 0) \times \prod_{j \in S_i} P(A_j(t) = 0) \quad (3)$$

(Note: This reflects the inter-cell communication where the NC queries neighbours $j \in S_i$).

(3) Objective Function

The Network Controller (NC) periodically re-calculates G_i for each BS to minimize the Network Cost Function (J):

$$\min_{G_i} J = w_b \cdot P_{b,i} + w_d \cdot P_{d,i} \quad (4)$$

Subject to:

$$0 \leq G_i < N_i \quad (5)$$

$w_b + w_d = 1$ (Weighting factors where $w_d > w_b$ to prioritize handoffs).

$$P_{d,i} \leq P_{d,max} \text{ (QoS constraint for handoff dropping)}$$

Algorithm 1: Coordinated Network-Aware Guard Channel (CNAGC) Algorithm

The algorithm is divided into two parts: the Local BS Admission Control (real-time) and the Global NC Optimization (periodic)

Part A: Local Admission Control (at Base Station)

Input: Incoming request (New Call or Handoff).

1. Monitor State: Calculate $A_i = N_i - C_i$

2. Identify Request Type:

If Request = New Call:

If $A_i > G_i$: Allocate channel and admit call.

Else: Block call.

If Request = Handoff:

If $A_i > 0$: Allocate channel and admit handoff

Else: (Local cell is full) \rightarrow Initiate Coordination.

1. Send urgent query to NC/Neighbouring BSs via inter-cell link.

2. NC checks A_j for all $j \in S_i$

3. If any $A_j > 0$: Authorize Handover to target cell j .

4. If all $A_j = 0$: Drop handoff call.

Part B: Network-Aware Guard Channel Update (at Network Controller)

Input: Real-time data from all BSs, Δt (Update Interval).

1. Data Aggregation: Every Δt , collect C_i , $\lambda_{n,i}$ and $\lambda_{h,i}$ from all BSs.

2. Global State Update: Update the Global Network State Database (GNSD).

3. Predictive Analysis:

Calculate predicted handoff traffic $\lambda_{h,i}^{pred}$ based on MS mobility patterns and neighbor cell loads.

4. Optimization:

For each cell i , solve the optimization problem:

$$G_i^* = \arg \min(w_b P_{b,i} + w_d P_{d,i}) \quad (6)$$

Adjust G_i based on the predicted handoff intensity: If neighbouring cells are highly congested, increase G_i locally to ensure safety.

5. Command: Transmit new G_i values to all respective Base Stations

6. Repeat at next interval Δt

Simulation Framework

To evaluate the performance of the proposed Coordinated, Network-Aware Guard Channel (CNAGC) scheme, a discrete-event simulation was conducted. This framework allows for the observation of stochastic call arrivals, handoff triggers, and the dynamic response of the Network Controller (NC) under varying traffic intensities.

Simulation Setup

The simulation models a multi-cell cellular topology consisting of 19 hexagonal cells arranged in a wrap-round grid to eliminate edge effects and simulate an infinite network environment. Mobile Stations (MSs) are initially distributed uniformly across the network.

i. Mobility Model: User movement is modeled using the Random Waypoint Model (RWP), with speeds varying between 10km/h (pedestrian) and 80km/h (vehicular) to simulate diverse urban mobility.

ii. Traffic Modelling: Both new call arrivals (λ_n) and handoff arrivals (λ_h) follow a Poisson process. The channel holding time and cell residence time are modeled using exponential distributions.

iii. Coordination Logic: The simulation implements the inter-cell communication link where a Base Station (BS) can query its six immediate neighbours via the NC when local guard channels are exhausted.

Simulation Environment

The simulation was implemented using MATLAB R2023b with the Communications and Optimization Toolboxes. The environment was configured to run 10^6 call events per scenario to ensure statistical significance and a 95% confidence interval.

- i. Software: MATLAB (Discrete-Event Simulation Scripting).
- ii. Hardware: Workstation with Intel Core i7 CPU, 16GB RAM, operating on Windows 11.

- iii. Update Frequency: The Global Network State Database (GNSD) and the guard channel thresholds (g_i) are updated by the NC every $\Delta t = 20$ seconds

Simulation Parameters

The performance of the CNAGC scheme was compared against Fixed Guard Channel (FGC) and Dynamic Guard Channel (DGC) schemes using the parameters listed in Table 1.

Table 1: Simulation Parameters and Values

Parameter	Value
Total Channels per Cell (C_i)	50
Fixed Guard Channels (for FGC) (G_{fixed})	5
Initial Guard Channels (for CNAGC/DGC) $g_i(0)$	3
Mean Call Duration ($1/\mu$)	120 seconds
Mean Cell Residence Time ($1/\eta$)	90-180 seconds
New Call Arrival Rate (λ_n)	0.5-5.0 calls/min
NC Update Interval (Δt)	20 seconds
Priority Weighting Factors (α, β)	$\alpha = 0.3, \beta = 0.7$
Target Handoff Dropping Prob. (λ_{drop}^{target})	<3%
Number of Cells N	19 (Hexagonal)

To represent the ‘‘Traffic Scenarios’’ mentioned in the results, five specific profiles were defined:

- i. Low Load: $\lambda_n = 1.0$ calls/min; Low mobility.
- ii. Medium Load: $\lambda_n = 2.5$ calls/min; Moderate mobility.
- iii. High Load: $\lambda_n = 4.5$ calls/min; Moderate mobility.
- iv. Handoff Heavy: $\lambda_n = 2.0$ calls/min; High mobility (Short residence time)
- v. Non-Uniform (Congested): Hotspot cells with $\lambda_n = 5.0$ calls/min surrounded by low-load cells.

RESULTS AND DISCUSSION

To evaluate the performance of the CNAGC scheme, we developed a simulation model and compared it against a traditional Fixed Guard Channel (FGC) scheme and a Dynamic Guard Channel (DGC) scheme (e.g., the Adaptive Guard Channel scheme from (Ojesanmi et al., 2021)). The DGC scheme dynamically adjusts guard channels based only on the local cell’s handoff arrival rate, without explicit inter-cell communication for coordination.

Handoff Dropping Probability

Figure 3 shows that CNAGC consistently achieves the lowest handoff dropping probability across all traffic scenarios. This is a direct consequence of its network-aware coordination. By actively communicating with neighbouring cells and the NC, the system can proactively identify potential target cells with available resources, including guard channels, and make informed handoff decisions. In high-load and handoff-heavy scenarios (Traffic scenarios 3 and 5), where traditional schemes struggle significantly, CNAGC demonstrates a substantial reduction in dropped calls. For instance, in the ‘‘Handoff Heavy’’ scenario, CNAGC’s handoff dropping rate is 2.5%, significantly lower than FGC’s 6.8% and DGC’s 5.5%. This superiority stems from the NC’s global view, which enables it to re-allocate guard channels more effectively where they are mostly needed, based on predicted handoff trajectories and real-time resource availability in adjacent cells.

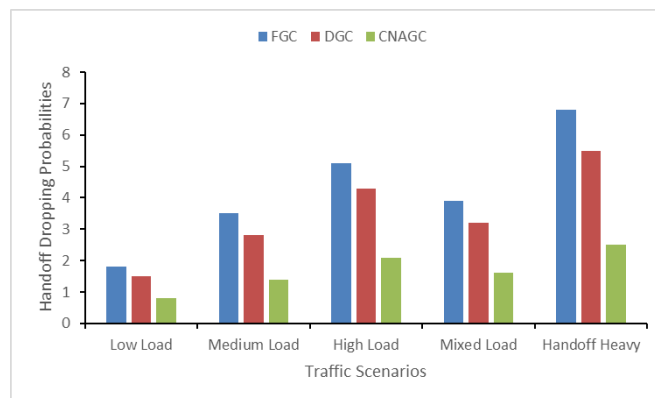


Figure 2: Handoff Dropping Probabilities against Traffic Scenarios

New Call Blocking Probability

In figure 3 CNAGC scheme maintains competitive, and often superior, new call blocking probabilities compared to FGC and DGC. This is because the dynamic and coordinated

allocation of guard channels prevents excessive channel reservation in cells with low handoff activity, making more channels available for new calls. in the ‘‘High Load’’ scenario, CNAGC has a new call blocking rate of 4.8% which is better

than FGC's 7.2% and DGC's 6.5%. The optimization algorithm in the NC effectively balances the trade-off between prioritizing handoff calls and admitting new calls, guided by the weighting factors.

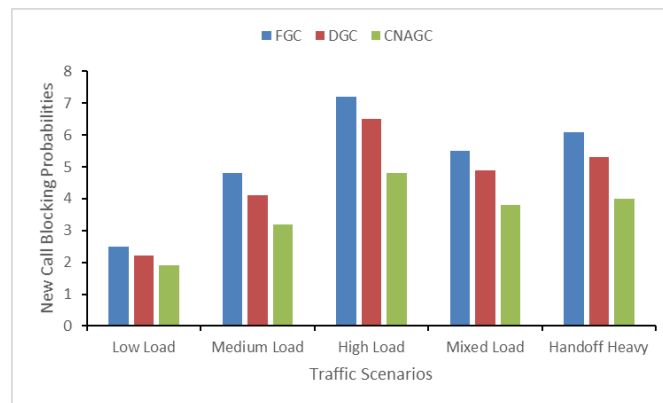


Figure 3: New Call Blocking Probabilities against Traffic Scenarios

Channel Utilization

In figure 4, the CNAGC scheme exhibits the highest channel utilization among the compared schemes. This is a crucial benefit of its network-aware design. By dynamically adjusting guard channels and coordinating resource allocation across cells, the scheme ensures that channels are not idle

unnecessarily. In the "Medium Load" scenario, CNAGC achieved 82% utilization, surpassing FGC's 75% and DGC's 78%. This efficiency is particularly evident in scenarios with uneven traffic distribution, where CNAGC can shift resources or guide handoffs to less congested areas, thereby maximizing the use of the entire network's capacity.

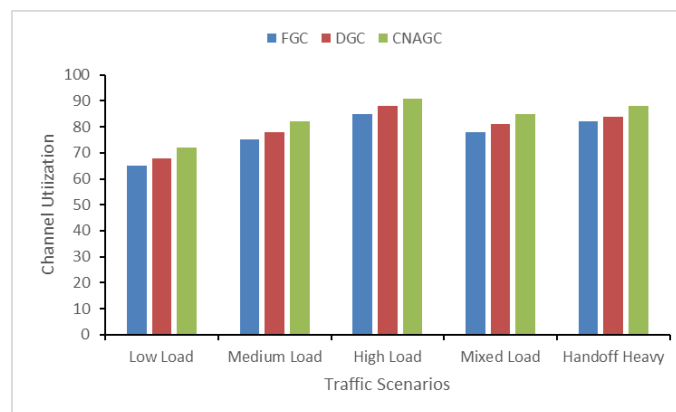


Figure 4: Channel Utilization against Traffic scenarios

CONCLUSION

This paper presented the Coordinated, Network-Aware Guard Channel (CNAGC) scheme with inter-cell communication for efficient resource management and enhanced call admission control in cellular networks. The proposed architecture integrates a centralized Network Controller with distributed inter-cell communication links to achieve dynamic and optimal guard channel allocation. The mathematical model and algorithm formalize the decision-making process, aiming to minimize a weighted sum of handoff dropping and new call blocking probabilities.

Simulation results demonstrate that the CNAGC scheme significantly outperforms traditional Fixed Guard Channel (FGC) and Dynamic Guard Channel (DGC) schemes in terms of reducing handoff dropping probability, lowering new call blocking probability, and improving overall channel utilization. The ability of CNAGC to leverage both global network intelligence and real-time local communication provides a robust and adaptable solution for handling mobility in modern wireless networks. This scheme is particularly well-suited for dense and dynamic cellular environments, where efficient handoff management is paramount for maintaining high QoS and user satisfaction.

Future work could explore the integration of machine learning for more accurate handoff prediction and autonomous adjustment of weighting factors, as well as extending the scheme to heterogeneous networks with different radio access technologies.

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