DISTRIBUTED MULTI-AGENT SOFT ACTOR-CRITICS FOR CLI MITIGATION IN DYNAMIC SBFD-TDD CONFIGURATION FOR 6G NETWORK

TESIS

BUDIMAN
55424120007

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FAKULTAS TEKNIK
UNIVERSITAS MERCU BUANA
JAKARTA
2026

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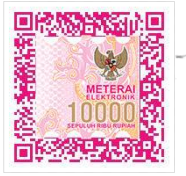

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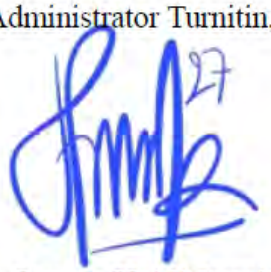

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ABSTRAK

Sub-Band Full Duplex (SBFD) menjanjikan perbaikan besar pada kapasitas uplink jaringan 5G-Advanced dan 6G, tetapi manfaat ini tidak stabil di semua kondisi trafik dan memunculkan masalah baru berupa *cross-link interference* (CLI) terhadap sel di sekitarnya (*neighbor cell*). Penelitian ini bertujuan untuk mengevaluasi apakah pendekatan multi-agent reinforcement learning terdistribusi, yaitu Multi-Agent Soft Actor-Critic dengan skema Centralized Training Decentralized Execution (MASAC-CTDE), mampu memilih konfigurasi frame SBFD-TDD secara dinamis dan lebih baik dalam menyeimbangkan *throughput*, *fairness* antar sel, dan CLI dibanding pendekatan statis, heuristik, maupun agen SAC terpusat (SAC-global). Variabel yang diteliti meliputi *throughput uplink* dan *downlink*, *throughput cell-edge*, *proxy* CLI, *proxy* antrian P95, *Jain fairness index*, serta perilaku konvergensi pelatihan (*entropy* dan *episodic return*). Data diperoleh dari simulasi system-level pada skenario *Urban Macro* beranggotakan 21 sel, dievaluasi pada lima tingkat beban trafik (ρ = 0,10 hingga 0,90), sepuluh model konfigurasi, dan tiga *seed* pelatihan mandiri, dengan agregasi hasil bertingkat tiga (per-episode, antar-*seed*, antar-beban) serta verifikasi formula terhadap hasil simulasi. Hasil menunjukkan MASAC dengan pertukaran informasi (MASAC-IE) dapat mempertahankan 95-99% *throughput baseline* heuristik pada beban rendah hingga menengah tapi kemudian turun ke sekitar 80% pada beban tinggi (ρ = 0,70) sebelum pulih ke level sekitar 95% pada ρ = 0,90, sementara *Jain fairness index* tetap di atas 0,9715 pada seluruh beban dan memenuhi kriteria keberhasilan ≥0,95. Pertukaran informasi antar-agen justru hanya memperbaiki CLI pada beban menengah (ρ = 0,50) dan tidak konsisten pada beban lain, sedangkan *proxy* antrian P95 menjadi titik lemah terutama pada kondisi beban jaringan yang berat. Secara keseluruhan, penelitian ini menyimpulkan bahwa MASAC-CTDE adalah pendekatan yang layak dan dapat dijelaskan secara mekanistik untuk mitigasi CLI pada SBFD-TDD dinamis, dengan beberapa kompromi atau konsekuensi yang perlu dipertimbangkan secara matang sebelum diterapkan pada jaringan komersial.

Kata Kunci: SBFD-TDD, MASAC-CTDE, cross-link interference, reinforcement learning multi-agen, *Jain fairness index*

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ABSTRACT

Sub-Band Full Duplex (SBFD) promises a real jump in uplink capacity for 5G-Advanced and 6G networks, but the gain is uneven across traffic conditions and brings a new problem: cross-link interference (CLI) between neighboring cells. This research asks whether a distributed multi-agent reinforcement learning approach, specifically Multi-Agent Soft Actor-Critic under a Centralized Training Decentralized Execution scheme (MASAC-CTDE), can select SBFD-TDD frame configurations dynamically and strike a better balance between throughput, cross-cell fairness, and CLI than static, heuristic, or centralized SAC (SAC-global) approaches. The variables studied are uplink and downlink throughput, cell-edge throughput, a CLI proxy, a 95th-percentile queue proxy, the Jain fairness index, and training convergence behavior (entropy and episodic return). Data come from system-level simulation over a 21-cell Urban Macro scenario, evaluated across five traffic loads (ρ = 0.10 to 0.90), ten policy configurations, and three independent training seeds, with results aggregated in three stages, per-episode, across seeds, and across loads, and cross-checked against closed-form calculations. The results show that MASAC with information exchange (MASAC-IE) keeps 95-99% of the heuristic baseline's throughput at low-to-medium load, drops to about 80% at high load (ρ = 0.70), then recovers to about 95% at ρ = 0.90, while the Jain fairness index stays above 0.9715 at every load, meeting the ≥0.95 success threshold set for this research. Information exchange between agents only improves the CLI proxy at medium load (ρ = 0.50) and is inconsistent elsewhere, and the P95 queue proxy stands out as a clear weakness at high load. Taken together, the findings support MASAC-CTDE as a workable, mechanistically explainable approach to CLI mitigation in dynamic SBFD-TDD, with specific trade-offs that would need to be weighed before any real-network deployment.

Keywords: SBFD-TDD, MASAC-CTDE, cross-link interference, multi-agent reinforcement learning, Jain fairness index

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