ABSTRAK

Profesi nelayan memiliki risiko kecelakaan kerja yang tinggi dan membutuhkan infrastruktur komunikasi darurat yang andal. Teknologi LoRa *Mesh* berpotensi mengatasi keterbatasan jangkauan di lingkungan maritim, namun mekanisme penyiaran (*flooding*) konvensional seringkali menimbulkan *broadcast storm*, *overhead* transmisi yang tinggi, serta pemborosan konsumsi daya perangkat. Penelitian ini mengusulkan optimasi *routing broadcast* menjadi kebijakan *selective forwarding* menggunakan pemodelan *Graph Attention Network* (GAT) untuk memprediksi kelayakan transmisi *relay* pada tingkat jalur komunikasi (*edge-level task*). Simulasi jaringan maritim dieksekusi menggunakan simulator ns-3.41 secara deterministik, menghasilkan 2.241.402 rekaman transmisi *hop* yang digunakan untuk melatih model GAT berukuran 29.969 parameter dengan *F1-Score* sebesar 90,70%. Evaluasi performa dilakukan menggunakan pendekatan *off-policy* pada 1.023 kejadian darurat (SOS) dan divalidasi secara statistik melalui uji non-parametrik *Wilcoxon Signed-Rank* serta metrik Probabilitas Keunggulan (PS_{dep}). Hasil pengujian menunjukkan bahwa kebijakan GAT mampu meningkatkan keandalan pengiriman paket (*Packet Delivery Ratio*/PDR) dari 85,00% menjadi 89,20%. Selain itu, model GAT terbukti sangat efisien secara mutlak (PS_{dep} 100%) dengan mereduksi *overhead* transmisi hingga 4,8% dan menghemat konsumsi energi baterai sebesar 33,8%, dengan catatan latensi *end-to-end* menjadi *trade-off* dengan peningkatan sebesar 1,3% atau sekitar 30,1 ms. Dampak dari efisiensi ini semakin mengamankan status kepatuhan jaringan terhadap regulasi *duty cycle* AS923 dengan menekan rata-rata waktu mengudara (*airtime*) menjadi 0,89% (berada di bawah batas maksimal 1%). Penerapan *deep learning* berbasis graf pada jaringan LoRa *Mesh* maritim terbukti memberikan optimasi pertukaran (*trade-off*) yang menguntungkan antara efisiensi dan keandalan sistem keselamatan di lingkungan maritim.

Kata Kunci: Komunikasi Darurat, LoRa *Mesh*, *Selective Forwarding*, *Graph Attention Network*, *Packet Delivery Ratio*.

ABSTRACT

The fishing profession carries a high risk of occupational accidents and requires a reliable emergency communication infrastructure. LoRa Mesh technology has the potential to overcome range limitations in maritime environments; however, conventional broadcasting (flooding) mechanisms often lead to broadcast storms, high transmission overhead, and excessive device power consumption. This study proposes the optimization of broadcast routing into a selective forwarding policy using Graph Attention Network (GAT) modeling to predict relay transmission viability at the edge-level task. Maritime network simulations were deterministically executed using the ns-3.41 simulator, generating 1,602,864 hop transmission records utilized to train a 29,969-parameter GAT model, achieving an F1-Score of 90,70%. Performance evaluation was conducted using an off-policy approach on 1,023 emergency (SOS) events and statistically validated through the non-parametric Wilcoxon Signed-Rank test alongside the Probability of Superiority ($PSdep$) metric. The test results indicate that the GAT policy successfully increased the Packet Delivery Ratio (PDR) reliability from 85,00% to 89,20%. Furthermore, the GAT model proved to be efficient (PS_{dep} 100%) by reducing transmission overhead by 4,8% and saving battery energy consumption by 33,8%, with a noted trade-off in end-to-end latency, which experienced an increase of 1,3% or approximately 30,1 ms. The impact of this efficiency further secures the network's compliance status with the AS923 duty cycle regulation by suppressing the average airtime to 0.89% (well below the 1% maximum limit). The application of graph-based deep learning in maritime LoRa Mesh networks is proven to provide a highly beneficial trade-off optimization between efficiency and the reliability of safety systems at maritime environment.

Keywords: Emergency Communication, LoRa Mesh, Selective Forwarding, Graph Attention Network, Packet Delivery Ratio.