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Performance Evaluation of a WMSN-based System for Endangered Bird Monitoring

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1 Introduction

Wetlands are a critical and distinctive feature of the Earth that cover roughly 6% of its total area. These unique ecosystems are renowned for their exceptional biodiversity, hosting a diverse range of flora and fauna. They serve as essential habitats for tens of thousands of waterbirds during the winter or migration seasons. As waterbirds are highly sensitive indicators of environmental changes, monitoring their populations in wetlands is crucial. The present study focuses on Lake Tonga (Figure 1), a freshwater lake located in the El-kala National Parc in Algeria. The conventional approach for bird monitoring involves manual data collection using binoculars and cameras. However, this method suffers from various limitations, including disturbance of bird behavior, limited temporal and spatial coverage. To address these issues, alternative surveillance methods have been developed, such as radar and thermal imaging technology. However, these methods require expensive equipment and are often limited. Fixed sensors such as WMSN have been used to overcome these issues. The study introduces a monitoring system that leverages audio and visual sensors for the identification of endangered bird species. To overcome the limitations of WMSN, particularly in terms of bandwidth and energy, we propose minimizing the processing of visual data by capturing only relevant images using low-complexity local audio-based recognition before triggering the camera. While previous works have employed audio-visual data processing, they do not account for the overlapping of various environmental noises that may result in false identification of species. We implement a noise reduction technique before the audio-based recognition to ensure accurate and robust sound recognition.

2 Proposal and Performance Evaluation

The proposed local audio recognition system comprises three primary stages, namely denoising the sensed audio signal, feature extraction and classification [2]. In order to get some insight into the efficacy of our proposed architecture with respect to LLNs¹, experiments were conducted using the COOJA simulator. Three scenarios were considered S0, S1 and S2. In S0,

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1. Low Power and Lossy Network

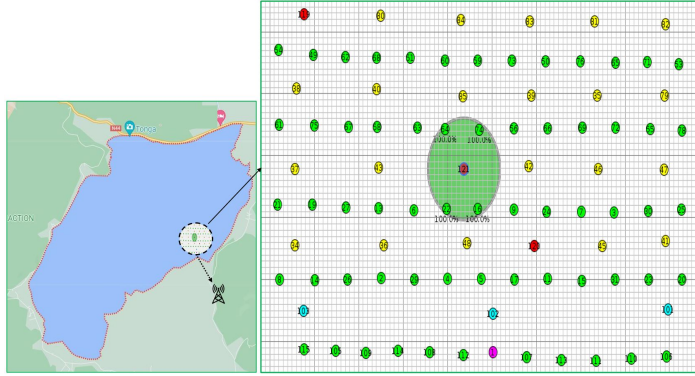


FIG. 1 – The network topology for the Tonga Lake (Algeria)

periodic image capture and transmission are performed without local audio identification. In S1, image capture and transmission were conducted only upon an audio detection of a target bird excluding the denoising phase. In S2, our proposal, operates as S1 but incorporates a denoising phase prior to audio identification. The sensor nodes were deployed in a cluster topology (Figure 1) across a $550m \times 960m$ square sensor field. The sink (node 1) was located at the center of the lower edge, three cluster head sensor nodes (in blue) were deployed in a single line, while the camera sources (in yellow) and audio sensors (in green) nodes were deployed in parallel, the audio sensors are also regarded as intermediary nodes. The transmission range is 80 meters. The sensor nodes were equipped with an IEEE 802.15.4 radio. It is important to note that the audio sensors are positioned at a specific distance from the birds, the audio signal was required to reach the acoustic node with a precise attenuation power for accurate audio processing. To estimate the attenuated signal power, the general signal power model of [1] was implemented. While the sensor possesses the capability to detect up to a distance of 150 meters, it should be noted that the level sound at this range may be low. For this reason, we suppose that if the audio signal detects a sound with a sound level less than 40 dB, no processing is applied. If the level exceeded 60 dB, the processing is automatically and locally performed. In cases where the level is between 40 dB and 60 dB, simple messages from the acoustic nodes are sent to the cluster head, which then determined which audio sensor should perform the processing based on a simple comparison of energy. To estimate power consumption, the Contiki provided Powertrace tool was employed. The performance evaluation metrics were averaged over 10 simulations conducted with varying random seeds. The sender transmitted data packets with a maximum payload of 96 Bytes. A check channel rate (CCR) of 16 and a CSMA protocol have been set. We suppose that during a day, 50 periods (T) were considered, where $T = 1$ min. If a target sound was detected, one captured image was transmitted in a single T. The bitrate differs across scenarios based on audio classification results in [2] and a probability of 0.3 was fixed.

Energy consumption. The study focuses on two metrics, namely the energy consumption and the energy consumption per useful visual data. The latter metric pertains to the ratio between the energy consumed and the number of pertinent images recorded for each of the three above-mentioned scenarios. Three varying positions of the camera source were examined (represented in red in Figure 1), situated at distinct locations, P1, P2 and P3, respectively. It is worth mentioning that simulations were performed individually for each camera position.

Figure 2 illustrates the energy required for image processing (including encoding and capturing) for the three scenarios during 50 periods of T. The resolution of the images under consideration is 512×512 . Notably, sound processing was not displayed in the figures, as it only accounts for 17% of the energy of single image processing, which is negligible compared to image consumption. The red line represents the ideal case where all captured images are of interest. According to the latter, S2 outperforms both S1 and S2, as 86% of the data sent is

of interest. The consumption is highest for S0, as more than 50% of unnecessary images were processed, which represents a waste of energy. For S1, consumption is the lowest, but in terms of useful energy, we do not capture most of the target images.

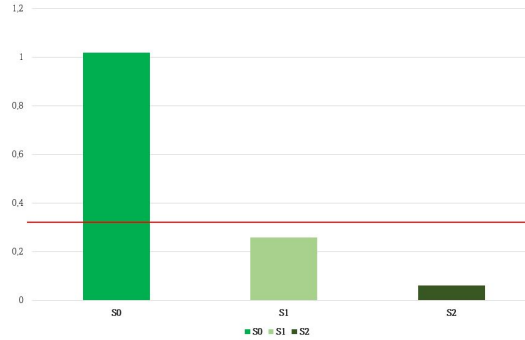
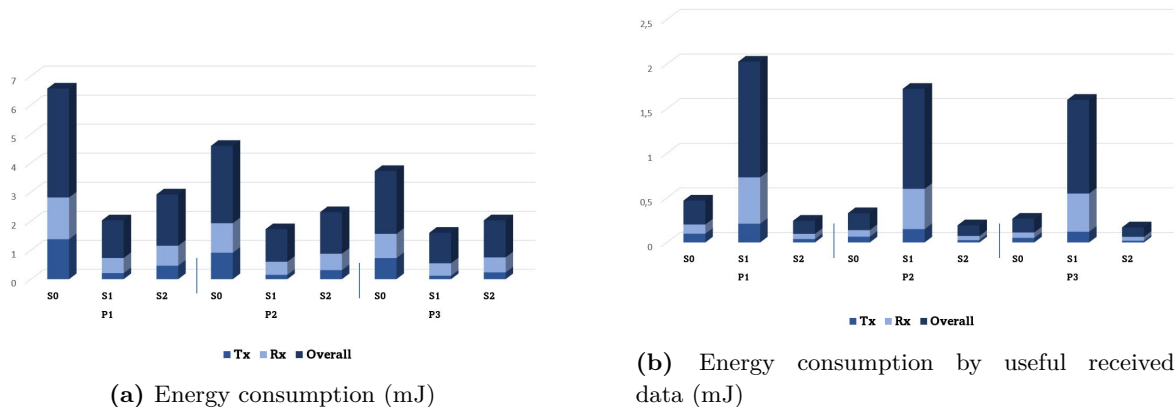


FIG. 2 – Image processing energy (Joules)

Figure (3a) illustrates the overall energy consumption (overall), calculated as the average consumed power over time, considering the individual power consumption records of various network nodes, as well as the transmission (Tx) and reception energy (Rx). The first notable observation is that there is a direct correlation between the distance separating the camera source and the sink, and the resultant escalation in energy consumption. This is attributed to the augmented number of hops required to reach the sink. Thus, the receive and transmit activities are increased. The second observation reveals that S0 exhibits higher energy consumption than both S1 and S2, as images are sent without prior selection, in addition, retransmission of packets is performed if some of them are lost. Figure (3b) illustrates the ratio of distinct energy consumption presented in Figure (3a) by useful received data for each scenario. We notice that the ratio in S2 is comparatively the lowest, due to the fact that a vast majority of the transmitted visual data is deemed relevant, which is not the case for S0 and S1. In conclusion, the results confirm that S2 provides the best compromise between saving energy and receiving important visual data for bird monitoring.

References

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(a) Energy consumption (mJ)

(b) Energy consumption by useful received data (mJ)

FIG. 3 – Evaluation of different energies consumption of the network