Adaptive and Dynamic RF Systems Enabled by Bio-Inspired Photonics and Microwave Photonics

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Abstract: We introduce various bio-inspired and microwave photonic technologies for improving security, ensuring channel availability, and increase adaptability to environmental changes. Solutions from the nature are excellent candidates for tackling critical challenges in emerging RF systems.

1. Introduction

Our nature not just offers an incredible amount of natural resources to human, but also provides inspiration for the advancement of human technologies. Due to the high demand of multifunction anywhere and anytime wireless service, RF systems are being challenged to adapt to rapid changes that are associated with the change in service, security need, topography, and atmospheric properties. Animals have gone through millions of years of evolution, there are lots of strategies and neural algorithms that are designed and evolved to be effective for animals to adapt to their environment, to communicate effectively, and to survive from predators. Learning from the animals could be the natural solution towards the critical challenges in modern technologies. On the other hand, photonics has been offering promising solutions for emerging RF systems to tackle challenges that are too challenging for conventional electronics. Over the last decade, intensive research in the fields of neuromorphic photonics, bio-inspired photonics, and microwave photonics have proven their importance in advancing RF technologies. From highly dynamic RF systems based on photonic technologies [1], to small-scale photonic neural network that mimic brain like functions [2], to optical microstructure inspired by nature [3], the possibilities are endless. In this paper, we focus on the progress we made based on bio-inspired photonics and microwave photonics to improve the reliability, availability, and security of a dynamic and smart RF systems. We will introduce the optical implementation of jamming avoidance response in Eigenmannia, optical approaches for dynamic multiband RF filtering and wideband RF spectral tailoring, as well as the use of ocean camouflage strategies for optical steganography.

2. Jamming Avoidance Response (JAR) for Mitigating Jamming in Radar Systems

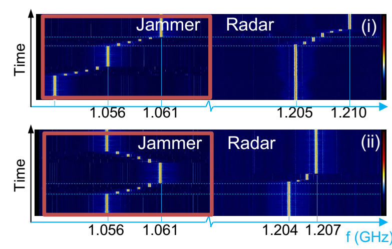

Fig. 1: RF spectral waterfall showing the optical JAR in action [4].

Eigenmannia, a gene of weakly electric fish uses electric field for social interaction and navigation. They have a unique jamming avoidance response (JAR) that mitigates frequency jamming from another close-by electric fish. In JAR, phase and amplitude information between the two electric fish are utilized to determine the direction of frequency shift needed when potential jamming occurs [4]. To mimic JAR in Eigenmannia using photonics, self-phase modulation in a semiconductor optical amplifier (SOA) and offset filtering is used to identify the zero crossing points in the reference electric field. Next, cross gain modulation in SOA is used to compares the phase between the beat signal (between the reference and the jammer) and the reference electric field to determine their phase relationship. Then, a temporal offset optical subtractor based on SOA is used for examining the beat signal envelope and identifies the rising and falling envelopes. Finally, an Arduino based logic unit takes in the amplitude and phase information, then uses them to determine whether the jammer is at a higher or lower frequency. The photonics-based JAR has been experimentally demonstrated and has successfully avoid jamming as the jammer is moving spectrally close by [4]. Fig. 1 shows the measured spectral waterfall of the JAR process, that shows its ability to ensure the availability of the communication channel under intentional and inadvertent jamming.

3. Dynamic Multiband RF Filtering and Wideband Spectral Tailoring for Adaptive RF Systems

Multi-function, high mobility, and continuous anywhere coverage demand of emerging RF systems require both terrestrial and non-terrestrial networks to support their operation, that results in dramatic changes in the transmission properties that would significantly degrade the system performance. To maintain the quality of transmission and enable adaptation in heterogeneous and multiband communications, there is a critical need of reconfigurable multiband filter for dynamically removing noise and interference, as well as a customizable spectral tailoring system to adapt to the dynamic usage of frequency spectrum.

We have designed a number of reconfigurable multiband RF filter [5-6] with tunable center frequency over 20 GHz range, reconfigurable number of passband from one to twelve, three different filter profiles, and independent chirp control. An example of multiband filter with independent chirp control is shown in Fig. 2(a). With a two-step algorithm that breaks down the target spectral response into a unique series of Gaussian functions, the multiband filter has been advanced into a customizable microwave photonic RF spectral shaper with over ten adaptive spectral control points over wideband operation frequency range of 10 GHz, covering S, C, and X bands simultaneously with step resolution of as fine as tens of MHz [7], as shown in Fig. 2(b).

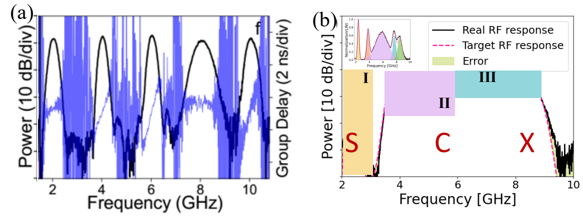

Fig. 2: Experimental results of (a) Reconfigurable multiband filter with independent frequency, number of passbands, spectral profile, and chirp control [6]; (b) Dynamic adaptive RF spectral shaper with optimized decomposition and reconstruction algorithm [7].

4. Optical Stealth Transmission of RF Signal Inspired by Camouflage Strategies of Marine Hatchetfish

Effective cryptography requires both encryption for scrambling and steganography for hiding the sensitive signal in plain sight. Most research effort have been focusing on encryption, however, steganography is an essential part of cryptography and cannot be overlook. We developed a RF steganography technique that is inspired by underwater camouflage strategies from Marine Hatchetfish – silvering and counterillumination [8]. Unlike conventional stealth technique that uses dispersion for spreading the pulse amplitude underneath the public channel and system noise, the bio-inspired approach uses interference to make the sensitive signal disappear from the attacker's eye. Silvering is achieved using photonic based finite impulse response (FIR) [5] while counterillumination is achieved using wideband optical comb carrier. In the attacker's eyes, the stealth signal is invisible in all domains including temporal, RF spectral, and optical spectral domains, as shown in Fig. 3(a). With a legitimate stealth receiver at the designated location, the sensitive OFDM signal can be recovered successfully [8].

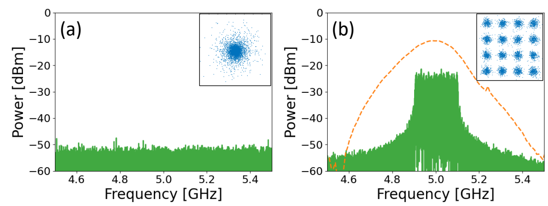

Fig. 3: (a) Stealth signal is invisible to the attacker (b) Stealth signal reappears at the designated stealth receiver [8].

5. Summary

We have introduced a number of photonics enabled and bio-inspired technologies that effectively facilitate the flexibility, security, and adaptability of emerging RF systems.

Acknowledgement

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