Digital signal processing for high-capacity indoor optical wireless communication systems

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Credit: Liuyan Chen

With our increased use of smartphones and need for real-time video, future indoor networks are expected to provide seamless wireless coverage while at the same time supporting higher connection density and higher capacity with high power efficiency. As a result, traditional radio-based wireless communication, in other words WiFi, will struggle to meet these demands. One way of addressing this is to use optical wireless communication networks. For her Ph.D. research, Liuyan Chen focused on advanced signal processing using high-efficiency digital signal processing techniques to improve the capabilities of OWC networks.

Optical wireless communication (OWC) is a promising approach that can supplement traditional indoor networks. A concept of two-dimensional (2D) infrared (IR) beam-steered OWC that uses narrow infrared beams for information transmission has been proposed for high-capacity indoor OWC systems by Ton Koonen.

The narrow beams of OWC can be steered to different directions, and each beam serves just a single user device, such as a laptop or smartphone. Thus, a person can enjoy a dedicated, high-speed connection to the Internet without congestion and privacy issues.

Meanwhile, the low-complexity, high-efficiency digital signal processing (DSP) technique has benefited OWC systems as it improves the spectrum efficiency and signal quality, while boosting the system capacity in a cost-efficient manner. In her Ph.D. research, Liuyan Chen focused on advanced signal processing using DSP techniques to take care of processing the wireless signals and preparing them for the OWC system at high connection densities and at Gigabit-per-second capacity, far beyond what current radio-based (Wi-Fi) systems can achieve.

Digital Nyquist filtering

In a 2D IR beam-steered OWC system using optical AWGR modules, a larger beam-steering spatial resolution (denser AWGR grid) is required to achieve larger wireless spatial coverage and higher wireless connection densities. However, this comes at the cost of a compromised OWC capacity per beam.

Chen proposed to take advantage of the digital Nyquist filtering technique to solve this problem. By shaping the transmitted signal for narrow spectral occupancy with high out-of-band suppression, the inter-channel crosstalk resulting from the imperfect AWGR filtering can be reduced, which enables using a denser AWGR grid. Also, a larger channel capacity is attainable with the improved spectrum-efficient signal. The proposed method has been experimentally demonstrated over a 6-GHz bandwidth-limited AWGR-based 1.1-m IR OWC link with the 20-Gbit/s OWC capacity using PAM-4 format.

Non-integer oversampling

As the cost of eliminating the trade-off between OWC capacity per beam and beam-steering spatial resolution, the digital Nyquist filtering leads to additional hardware implementation complexity. The resulting doubled sample rate requires expensive higher-speed data converters.

To address this, Chen proposed the use of a non-integer oversampling approach to reduce the hardware implementation complexity and power consumption of this system. Chen experimentally verified the approach and investigated the impact of the non-integer oversampling in the 12.5-GHz channel-spaced 6-GHz bandwidth-limited AWGR-based 1.1-m IR OWC link with a 20-Gbit/s capacity. The sample rate is minimized to a 1.1-fold symbol rate with an 11-GS/s DAC sample rate. Comparing to the 2-fold oversampling Nyquist PAM-4 system, the DAC sample rate requirement is relaxed by 55%, with a cost of a 2.3-dB power penalty at the 7% FEC limit of 1×10^{-3}.

Parallel architecture

Low-complexity DSP techniques are proven to be efficient for low-cost high-capacity OWC systems. In an effort for practical realization, Chen also implemented the real-time DSP based on the FPGA platform.

But the classical semi-parallel implementation architecture introduces severe latency due to the massive intermediate data caching, which hinders the latency-critical applications. Hence, Chen proposed a deeply parallel architecture that requires no massive intermediate data caching to reduce the total DSP-introduced latency. An FPGA-based real-time PAM-4 receiver with deeply parallel fully-pipeline DSP implementation is experimentally demonstrated in a fiber link.

The proposed solutions from Chen's research hold great promise for future high-capacity high-wireless-connection-density indoor networks.

More information: Digital-signal-processing for high-capacity indoor optical wireless communication systems. research.tue.nl/en/publication … ndoor-optical-wirele

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