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Metacrystals as Smart Structures: Unpowered Directional Routing Meta-structure (UDRM) for Passive Intelligent Signal Engineering

As the demand for faster internet, improved bandwidth, and enhanced data security grows, researchers from Stanford and Aalto University have introduced metacrystals—a novel class of passive intelligent surfaces designed to revolutionize wireless communication. These advanced structures offer energy-efficient, cost-effective solutions while enabling complex signal multiplexing.

Metacrystals are volumetric dielectric composites engineered through inverse design algorithms and computer optimization to achieve precise electromagnetic properties. Their three-dimensional geometry provides expanded design freedom, allowing them to simultaneously manipulate multiple signal parameters, including polarization, angle of incidence, frequency, and orbital angular momentum. This makes them far more versatile than traditional intelligent surfaces.

Designed for seamless integration into building walls, metacrystals can reroute and enhance wireless signals in both indoor and outdoor environments, improving communication networks. Their binarized permittivity contrast enables fabrication via additive manufacturing, making them scalable and practical for deployment at frequencies up to 100 GHz.

With high versatility, scalability, and energy efficiency, metacrystals mark a technological breakthrough in sustainable smart living and next-generation wireless infrastructure.

Stage of Development: Prototype

Applications

- **Fifth-generation (5G) communication networks**
- **Beyond 5G (B5G) and sixth-generation (6G) communication networks**
- **Wireless communication**
- **Mobile communications**
- **Internet-of-Things (IoT)**
- **Holography**

Advantages

- **Extremely high efficiencies** - up to 100% possible
- **Zero power consumption** - provides entirely passive directional routing of beams
- **Low-cost, large-scale** fabrication via 3D printing
- **Sustainability** - materials used for UDRM fabrication are recyclable
- **Versatility** - Can achieve simultaneous directional routing of the frequency channels. Can be designed for transmit or reflect mode of operation. Can be used indoor and outdoor.
- **Security** - in contrast to omnidirectional technology, it can provide additional security by limiting the signal into a given direction

Publications

- Asgari, M. M., Catrysse, P. B., Wang, H., Fan, S., & Asadchy, V. (2024). Multifunctional passive metacrystals for enhancing wireless communications. arXiv preprint arXiv:2412.05699.

Patents

- Published Application: WO2025054475

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