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Strategies for mitigating hidden node challenges to enhance performance and reliability in IEEE 802.15.7 MAC layer wireless networks : A comprehensive survey

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Abstract

One of the major breakthroughs in wireless communication technology is represented by Visible Light Communication (VLC) standardised at ISO level within IEEE 802.15.7 Due to its advantages i.e., high transmission rates, security and immunity from electromagnetic interference as opposed to relatively microwave counterparts crucial for QoS assessment example video streaming application. Nonetheless, the hidden node problem poses a serious challenge in Medium Access Control (MAC) layer of these networks and renders collisions, degraded throughput and increased latency affecting its performance as well as reliability of communication system. In this survey paper, the authors review all of the literature on how to address hidden node problems in IEEE 802.15.7 MAC layer wireless networks extensively. The strategies and schemes proposed for addressing this conflict include modifications in the MAC protocol, introduction of sophisticated collision avoidance mechanisms or cooperative communication methods. Moreover, we evaluate the performance of these solutions under distinct network scenarios with a focus on important metrics like throughput, latency and packet delivery rate. The current approaches are discussed and evaluated in which the paper suggests, on-line or real-time investigations that allow to study more specific scopes of behavior. Ultimately, our survey is meant to be a highly useful resource for researchers and industry practitioners in the field, providing an overview of existing state-of-the-art solutions that shall lead future work towards more reliable/efficient VLC systems. This paper analyzes all MAC layer solution methods of IEEE 802.15.7 to help developers build an efficient and reliable wireless network for their applications with optimal performance.

Subject Classification: *90B18.*

Keywords: *IEEE 802.15.7, Hidden node problem, Collision avoidance, Communication reliability, MAC layer challenges, Optical wireless communication, Visible light communication, Wireless networks.*

1. Introduction

VLC is done through the visible light spectrum, and IEEE 802.15.7 is a major technology in this field. Compared to basic radio frequency (RF)

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technology this one has higher data rates as well as cost advantages. Nonetheless, challenges are a reality for VLC, especially at the MAC layer since hidden node challenge affects the overall network performance and reliability [1]. The hidden node problem occurs when a specific node falls within the range of a given access point and does not come within radio range of all the other nodes communicating with this particular WAP. This leads to collision as the hidden node cannot sense packets in the air and thus it transmits at the same instant therefore overwriting the current transmission and leading to packet drop [2].

In IEEE 802.15.7 networks, this problem is even more severe because of VLP characteristics and the need for sight propagation to create a link. Researchers have thus offered several solutions to minimize or eradicate the hidden node problem in IEEE 802.15.7 MAC layer wireless networks based on a number of strategies and methods. One of them is to alter the MAC protocol, which may not be suitable for these technologies. Some researchers have suggested improvements to such protocols and changes that can be made to the current one, for instance, using additional signalling methods like RTS and CTS frames to ensure that all the nodes in a certain network are informed of transmission in progress [3].

However, these potential gains are accompanied by the high overhead and/or worsened latency from using extra signalling [4]. One other related but even more interesting form of this concept is the consideration of enhanced collision avoidance techniques, including adaptive rate control and TDM. These methods pursuit to reduce the impact of collisions by adjusting the transmission parameters based on current network behavior. Cooperative communication techniques are also potential solutions to the hidden node problem in VLC networks as they qualify each node to relay information and extend their communication coverage actively; hence, the hidden node perception is significantly reduced. Other approaches for handling hidden node have been proposed in which VLC is integrated with other conventional wireless technologies such as RF or even IRC.

Hybrid systems incorporate RF to communicate control information between APs and synchronize their transmission while utilizing VLC for data conveyance at high data rate. This method attempts to avoid the hidden node problem by creating another sort of communication to be used for planning so that there will be less likelihood that any two cousin nodes will transmit [5]. Nevertheless several issues and challenges still remain concerning the hidden node problem solution in IEEE 802.15.7 MAC layer wireless networks with a serious development on this. For instance, node mobility and changing lighting conditions of VLC networks cause a high level of channel dynamics, which require intricate solutions. More so, decision making about performance and system complexity in relation to overheads is especially important for real-world scalabilities. Consequently, the focus of this survey is to discuss the current progress of the VLC technology and present suggestions for further research on designing high-performance and energy-efficient wireless communication systems.

2. Orientation Towards OWC

Optical Wireless Communication (OWC) is a relatively new and innovative communication platform that employs light wavelength to transfer data through the environment. There are benefits compared with conventional radio waves, including higher data rate capability, confinement and co-channel interference and immunity to electromagnetic interference [6].

Thus, the advantages of OWC are more pronounced in terms of applications that require rapid and synchronous wireless transmission, in applications where RF communications can be implemented inefficiently or not at all. OWC modalities can be further divided by the type of light used. Visible Light Communication is the most commonly used subset of OWC, which employs a wavelength range of 400 – 700 nm. VLC systems use LEDs, which have flexibility in varying from high frequency to enable the light to remain on for data transfer without affecting the light [7].

This dual-use nature, therefore, makes it a good candidate for services such as indoor positioning and vehicular communication, as well as for giving Internet access to users in RF-sensitive settings. IRCOMM (Infrared Communication) IRC is but one of the subcategories of OWC, operating in the 700nm-1mm orbit band range. VLC has disadvantages, including weak penetration through materials, and it is interfered with by ambient light compared to IRC. Nonetheless, direct visibility between the transmitter and receiver is required up to this limit, strictly limiting its usage [8].

3. Hidden Node Problem

The hidden node problem (HNP) is a great threat for both RF and OWC networks due to collision and frames lose at the condition when nodes are out of transmission range of each other. Among the proposed ideas one of the possible approaches that can be used to address this problem is the hidden matrix based regrouping or HMR technique for identification of hidden node pairs at the Access Point (AP) utilizing PSPT timings [9].

The IEEE 802.11ax protocol being its future version has proposed to redesign the carrier sensing threshold to enhance the usage of WLAN spectrum through spatial reuse factor. The other type of asymmetry HNP arises at the time when older devices are associated with low CSTH while the new ones are associated with high CSTH hence a problem with access to this channel. Regrettably, in terms of the described problem, the RTS/CTS technique does not operate as intended [10].

In Namaste the Third Generation Partnership Project (3GPP) for lte in the unlicensed spectrum of 5 GHz band has introduced Licensed Assisted Access (LAA) and use the Listen Before Talk (LBT) similar to that of the Wi-Fi MAC. As for this capability, there is a parameter called Channel Quality Indicator (CQI) which helps to find so called hidden nodes. Intersection techniques are described in [10], where interferences and network characteristics are represented by parameters akin RSRP, CQI, and RSRQ. Employing the real time and statistically well-developed QoS features of the broadly applicable and relatively simple CPN model of The IEEE 802.11e protocol, the problem at hand and its behavior under different working conditions is examined here.

In [11], analysis of hidden terminals situation in VLC star topologies is provided to illustrate how hidden nodes that affect IEEE 802.15.7

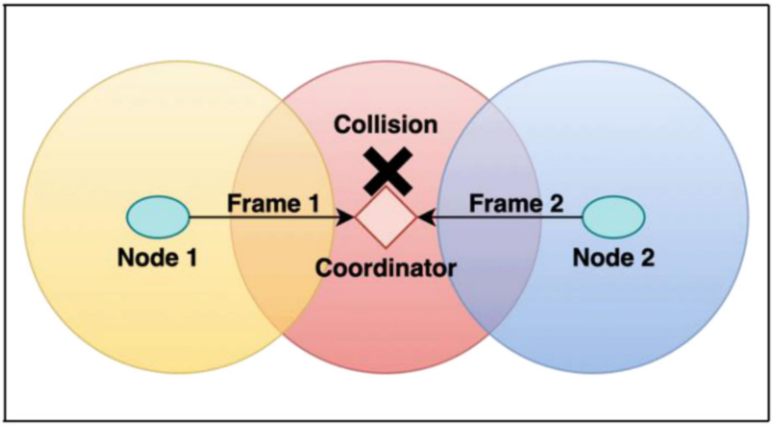

Figure 1

Collision occurrence due to hidden node problem as node1 is not in carrier sense range of node 2

upstream CAP. An experimental asymmetric hidden node aware metric (AHAM) is further proposed here which construct source destination paths that avoids hidden nodes which are disturbing the ongoing flow and hence provides network fair share and high throughput [12]. Figure 1 provides the collision occurrence due to the hidden node problem as nodel 1. Table 1 exhibits the summary of comparison of available methodology.

Table 1

Summary of comparison of available methodologies for HNP

Reference	Focus Area	Proposed Solution	Key Contributions	Limitations/ Challenges
Lee and Kim [1]	Overview of VLC systems and applications	Discussed the advantages of VLC and current applications	Comprehensive summary of VLC capabilities and challenges	Did not address specific MAC layer issues like hidden nodes
Faria, Tsai and Teo [2]	Recent developments in VLC	Explored performance improvements in VLC systems	Provided insights into design and application-specific requirements	Limited coverage of collision issues in VLC
Zhang and Lee [3]	Infrared communication advances	Introduced methods to enhance IRC efficiency	Highlighted IRC's complementary role in hybrid systems	Did not focus on hidden node mitigation
Schindler [4]	Ultraviolet communication systems	Proposed advanced techniques for UV communication	Analyzed potential benefits of UV communication in harsh environments	Irrelevant to visible light MAC layer challenges
Kumar, Nair and Kumar [6]	Interference mitigation in VLC systems	Proposed advanced collision avoidance techniques	Enhanced performance in high-density networks	Did not directly address MAC layer protocol improvements

Contd...

Rahman, Karim and Rahman [8]	VLC for indoor positioning	Proposed techniques for enhancing VLC-based positioning accuracy	Improved VLC utility in navigation systems	Limited discussion on MAC layer or collision problems
Wang, Zhang and Li [10]	Advances in optical wireless communication technologies	Discussed recent developments in OWC	Comprehensive review of OWC advancements	Limited applicability to MAC layer challenges
Kim and Kim [11]	Infrared wireless communication trends	Reviewed recent trends in IRC systems	Highlighted IRC potential in hybrid networks	Did not address MAC layer collision or hidden node issues
Tsai, Chen and Lin [12]	Ultraviolet communication for secure data transmission	Proposed secure UV communication implementation	Focused on secure transmission technologies	Irrelevant to VLC hidden node challenges

Now it has become crystal clear that we still have our task ahead of us. For example, researchers could look into handshake techniques and routing schemes that allow the best (zero or a minimal number of) hidden nodes to be involved. Finally, since OWC is all about mobility the next generation of research should work on dynamic carrier sensing: as a result with highly demanded active hidden node detection. Once more, overheads can be elevated to enhance power and latency.

4. Conclusion

The performance and reliability of IEEE 802.15.7 MAC layer wireless networks are crucial for addressing hidden node problems. Strategies and methods have been proposed to address this issue, including MAC protocol modifications, advanced collision avoidance methods, and cooperative communication methods.

Enhancements of MAC protocols like Request to Send/Clear frame exchanges can reduce collision probabilities, but they add extra overhead and latency. Advanced collision avoidance methods like adaptive rate control and time-division multiplexing offer throughput benefits and reduced interference, but require tight synchronization between players or specific mechanisms to adapt to network conditions.

Cooperative communication, which uses spatial diversity of different nodes, improves reliability and blocks out hidden node effects, but it also introduces additional complexity and increased synchronization requirements. Future research should focus on fine-tuning the trade-offs between performance, complexity, and overhead, as well as developing new techniques that fit within the rapidly evolving technology for modern VLC systems. Solving these problems can lead to better performance for future optical wireless communications systems (OWCS).

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