Medium Access Control (MAC) algorithm for Directional Optical Wireless Transceivers for Indoor Ad-Hoc Networking

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Abstract: This paper discusses our proposed MAC algorithm method for Indoor Optical Wireless Ad-Hoc Networking based on our transceiver circuit design, which utilises directional emitters and is fully controlled by microcontroller M16/C. Five control handshake signals namely; two directional Request to Send (RTS) signals, two directional Clear to Send (CTS) signals and two directional Acknowledgement (ACK) signals are used at the MAC algorithm for resolving potential collisions among the transceivers. By employing MAC algorithm, which enables the status of emitters and photodiodes at the transceiver to be either active or non-active, two known popular problems in ad-hoc network; the exposed and hidden terminal problems can be fully resolved.

1. Introduction.

Imagine in the situations such as the earthquake/volcanoes eruption disasters, when the rescuers need to quickly exchange information but all the communication infrastructures have collapsed because of the disasters. How is it possible to share information in these situations? The answer is communication via ad-hoc networking. Ad-hoc network is a network consists of collection of mobile terminals which communicating with each other without any infrastructure device such as a base station. The absence of the infrastructure device which normally organising and controlling the network (e.g. Wireless LAN) has made an ad-hoc network very challenging to manage.

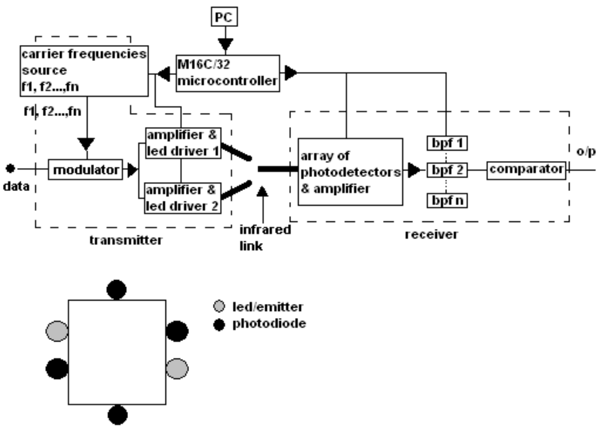
IEEE802.11 has specified two types of physical interfaces for Ad Hoc network; the radio frequency technology and the infrared band. Although there have been various studies about Ad Hoc Networking but most of them have been concerned with RF systems which theoretically have a few significance disadvantages compared to infrared (e.g. the need of licensing, lower bandwidth and etc.). References [1-2] reviewed the issues of optical wireless communications in general. Generally three important factors must be design efficiently in order to realise ad-hoc networking; the channel assignment algorithm, MAC algorithm and routing algorithm, which is needed for multihop communication between mobile terminals within an ad-hoc network.

MAC algorithms can be divided into two types; Single channel MAC and the Multichannel MAC. In single channel MAC, only one carrier frequency/channel is used to transmit any control handshakes signal while in multichannel MAC, multiple carrier frequencies/channels are used to convey the control handshakes signal. In single channel MAC algorithm, there have been many papers proposed attempting to reduce the hidden and exposed terminal problems e.g. [3-4]. In [4], the algorithm is adopted by IEEE 802.11 for wireless MAC in the Distributed Coordination Function (DCF) along with the CSMA scheme. However in [5], the author claimed that MACA and MACAW didn't fully resolve the hidden and exposed terminal problems. The probability of collisions between control handshakes signal is higher in a single channel environment as the number of mobile terminals participating in the an-hoc network increases. Therefore multiple channels [5-6] for control handshake signals are preferred as it can offers some significant performance improvement over single channel MAC algorithm such as; lower the probability of collisions between the control handshake signals, as they are conveyed on the different channels and hence higher throughput can be achieved.

The MAC algorithms mentioned above assumed omnidirectional antennas to convey any information. Although the omnidirectional antenna radiation is 360^{o} which offers better coverage but in certain applications omnidirectional antenna offers some disadvantages if the MAC algorithm is not carefully design to combat the hidden/exposed terminal problems and are more likely to interfere with neighbouring terminals. Therefore, directional antenna is more desirable as its radiation is focus into one direction and thus this will minimise interferences compare to omnidirectional antenna. A study has been conducted in [7], where the effort to compare between the omnidirectional and directional antenna-based MAC algorithms are done. Obviously from the discussions, directional antenna offers certain advantages against omnidirectional antenna. References [8-9], designed their MAC algorithm based on directional antennas. In [8], the MAC algorithm controls the directional antennas by setting them to active and passive modes. In this approach, the control handshake signals are only sent to the intended mobile terminal without interfering another mobile terminal. While in [9], although the directional antennas are exploited but additional device such as a GPS is needed to determine the physical locations of mobile terminals which will add costs to the system.

We have constructed three transceivers for indoor infrared wireless ad-hoc network utilising directional emitters to demonstrate our MAC algorithm. The rest of the paper is organised as follows; Section 2 describes the infrared transceivers in general. Section 3 discusses our proposed MAC algorithm and finally the conclusion in section 4.

2. Optical Wireless Transceiver



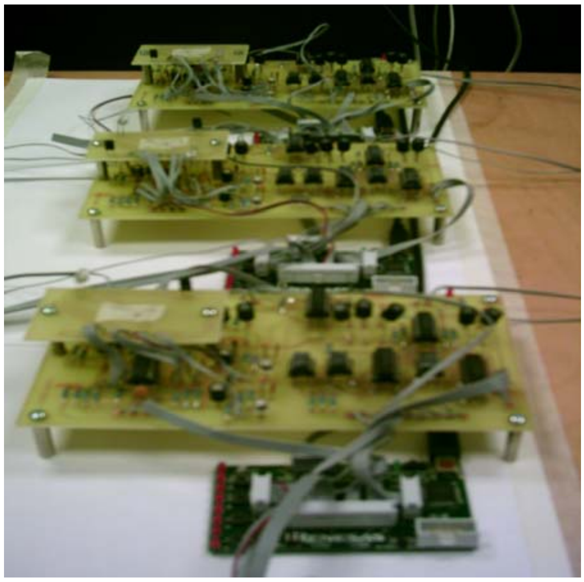


Fig. 1. Block diagram and layout of the transceiver

Fig. 2. Pictorial view of the transceivers

Fig. 1 shows the block diagram and the layout of the transceiver while fig. 2 shows the pictorial view of the transceivers. The operation of the transceivers is briefly discussed in [10]. A transceiver employs an on-off keying modulation method and equipped with two directional emitters where each one them is driven by the amplifier and the led/emitter drivers at the transmitter and it also has four photodetectors and corresponding band pass filters to pass the desired selected carrier frequencies, and are fully controlled by the microcontroller M16C and followed by the rectifiers and a comparator. It has a carrier frequencies/channels source which is programmabled via the M16/C microcontroller. It is set to generate five HF (high frequency) carrier frequencies (f1, f2, f3, f4 and f5) in the range of 2.5 to 8MHz. The directional emitters and photodiodes can be set to active/non active independently by M16C based on the MAC algorithm.

For brief operation a transceiver, assuming that a transceiver is assigned a carrier f1 which then modulated on-off keying the random data, and the modulated data is then amplified and transmitted via one of the emitters selected by the M16/C. Upon reception at the front end, the M16/C selects an appropriate photodetector which best receives the carrier f1, and it then goes through the process of amplification and rectification and subsequently passing through the corresponding band pass filter (bpf) for carrier f1, also selected by M16C, and it is then ‘squared up’ by the comparator to obtain the original data.

3. MAC Algorithm Description

This MAC algorithm has some similarity with IEEE 802.11 in which this algorithm is based on RTS, CTS and ACK control handshakes signal. It uses two RTS control signals(RTS1 and RTS2) and two CTS control signals(CTS 1 and CTS 2) and two ACK control signals (ACK1 and ACK2). Multichannel approach is adopted where RTS1, CTS1 and ACK1 are conveyed on unique channel f5, and the RTS2, CTS2 and ACK2 are conveyed via unique channel f4. In this approach the collisions between the control handshakes signal can be hindered. The microcontroller M16C can controls and switch the emitters and photodiodes to active or non-active status independently but based on unique internal and external "pairing combination".

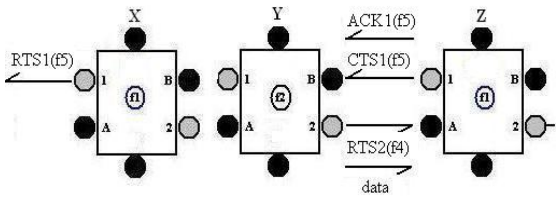


Fig. 3. Solving exposed terminal problem

The internal "pairing combination" is a unique pair of an internal emitter and a photodiode (e.g. emitter 2 is a pair of photodiode B and emitter 1 is a unique pair of photodiode A within a transceiver). If for example at transceiver Y receives any control handshake signals via photodiode B, if it requires to reply, it replies via emitter 2 not emitter 1. While the external "pairing combination" is a unique pair of an emitter and a photodiode at two different transceivers (e.g. emitter 1 is the pair of photodiode B, emitter 2 is the pair of photodiode A at the different transceivers). For example at transceiver Y, the photodiode B receives any control handshake signal during MAC protocol process transmitted from emitter 1 at transceiver Y, and based on this unique pair combination, indirectly transceiver X knows that particular control handshake signal is from transceiver Z not from transceiver X and if it require to reply, it will reply via emitter 2 and not via emitter 1.

As mentioned, two main problems exist in ad-hoc networking; the exposed terminal and hidden terminal problems. Let us consider fig. 3 to visualise the MAC algorithm operations and how it resolves exposed terminal problem. Assume transceiver Y wants to communicate with transceiver Z and the unique channels are assigned as in the circles. The channel assignment algorithm is already discussed in [10]. Transceiver Y issues RTS2 control signal via emitter 2 which is then conveyed on carrier frequency f4 to transceiver Z. At this time, transceiver Z is in idle state (non-active status), and upon receiving RTS2 control signal from transceiver Y via photodetector A, the microcontroller M16C at transceiver Z recognises that the RTS2 control signals is from transceiver Y which is from west direction (based on external "pairing combination") and based on internal "pairing combination", and if the RTS2 handshake signal is received above the signal threshold, it will reply with CTS1 control signal via emitter 1 which is conveyed on carrier frequency f5 to transceiver Y. If transceiver Y wishes to send any data message to transceiver Z, it does so through unique channel f2 via emitter 2. After data transfer has finished, transceiver Z acknowledges with ACK1 control signal which is conveyed on carrier frequency f5 via emitter 1 to transceiver Y and the communication is terminated when the transceiver Y receives the ACK1 control signal via photodetector B. Since transceiver X do not receive RTS2 control signal from transceiver Y, it can initiates another communication to any other transceiver (e.g. initiate RTS1 control signal via carrier frequency f5 to any other transceiver). If based on the IEEE802.11 MAC using the omnidirectional antenna were to employ, the RTS control signal issued by any transceiver can also be heard by another transceiver which the signal is not meant intended to it and this could result with the exposed terminal problem, where that particular transceiver X has to back up and cannot initiate its own communication.

From figure 4, assume transceiver Z is communicating with transceiver Y and transceiver X join the network. As mentioned before, the microcontroller M16C can control independently the emitters and photodiodes but based on unique internal and external "pairing combination". In this case while transceivers Y and Z are communicating, even though the internal and external "pairing combinations" at the other side of transmitter Y (the side facing transceiver X) do not play any role for communication between transceiver Y and Z, but they are in the idle/ready state and can be made active if any of the communication links required. If transceiver X wants to communicate with transceiver Y, it will issue RTS2 control signal via carrier frequency f4. If the RTS2 control signal is received above the threshold, photodetector A which is in idle state, receives the signal and is made active and based on the internal "pairing combination" emitter 1 at transceiver Y is also active and it reply with CTS1 via carrier frequency f5. Transceiver X received it via photodetector B and can begin sending data. In this way, transceivers X and Y can communicate with each other while transceiver Y and Z are communicating. At this moment microcontroller M16/C at transceiver Y switches concurrently the pairs of communicating transceivers (e.g. communication with transceiver X and Y) and this will hinder the hidden terminal problem.

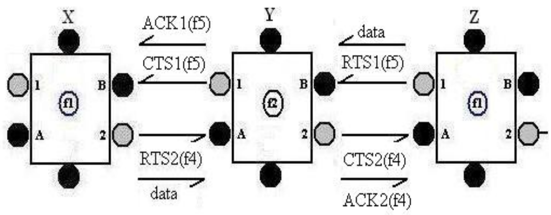


Fig. 4. Solving hidden terminal problem

4. Conclusions.

In order to best utilise the directional emitters in our transceivers design, a MAC algorithm must be designed accordingly to exploit the features of the directional emitters. By employing the Multichannel MAC algorithm concept, it can minimise the interference between the control handshakes signal and earn more gain/power and with some additional features such as switching the status of emitters and photodiodes to active and non-active, the exposed and hidden terminal problems can also be hindered.

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