MAC protocol for resource allocation in hotspot microcell

S.W. Kim, B.-S. Kim and Y. Fang

An easy solution is proposed that can be implemented at the access point in the MAC layer without modification of the standard for stations. The solution aims at providing a controllable resource allocation method between uplink and downlink traffic flows and adapting the parameters according to the dynamic traffic load changes.

Introduction: Low-cost and high-speed wireless local area networks (WLANs) are becoming increasingly integrated within the cellular coverage to provide hotspot coverage for high-speed data services [1]. WLAN offers a possibility for cellular operators to provide additional capacity and higher bandwidth for end users without sacrificing the capacity of cellular users, since WLANs operate on unlicensed frequency bands. In the distributed co-ordination function (DCF) of the IEEE 802.11 medium access control (MAC) protocol, a set of wireless stations (STAs) communicate with each other using a contention-based channel access method, namely carrier sense multiple access with collision avoidance (CSMA/CA). Since the DCF protocol allows equal chance to access the medium for all hosts, access point (AP) and STAs have equal utilisation to the medium. Thus, the DCF gives advantage to the uplink (from STAs to AP) transmission as the number of STAs increases. However this form of random access protocol is not recommended for asymmetric traffic loads in hotspots where the required utilisation of radio resource is strongly biased towards the downlink (from AP to STAs) [2–4]. Thus, when the downlink has much more offered traffic load than the uplink, the downlink becomes a bottleneck of system capacity and many more APs should be deployed to accommodate such STAs. We propose an improved DCF protocol that can control the utilisation ratio between the uplink and the downlink according to the required value.

Principle of operation: Uplink (downlink) utilisation is defined as all the time durations used for successful data transmissions on the uplink (downlink). Furthermore, system utilisation is defined as the sum of the downlink utilisation and the uplink utilsation. We define a required utilisation ratio between the uplink and the downlink as ψ such that

$$\psi = \frac{\text{required downlink utilisation}}{\text{required uplink utilisation}} \qquad (1)$$

When the current utilisation ratio between the downlink and the uplink is less than ψ, the AP can transmit data frames using point interframe space (PIFS) following the previous acknowledgement (ACK) frame. Since STAs transmit data frames after sensing that the medium is idle for at least a DCF interframe space (DIFS) which is longer than the PIFS, the AP can transmit data frames without collision in case of the PIFS usage.

A network operator may set the value of ψ or the AP may update the value of ψ to keep up with the dynamic changes of traffic load conditions. To allocate the network resource according to the offered load, we propose a dynamic update method of ψ. The AP has an internal memory that records the source MAC address of uplink data frames and the destination MAC address of downlink data frames for a time window of W. Let $u(t)$ and $d(t)$ denote the number of the source MAC addresses of the uplink traffic and the number of the destination MAC addresses of the downlink traffic between time t-W and t, respectively. For example, if an uplink data frame is transmitted with a new source MAC address that is not registered in the AP memory, $u(t)$ increases by one and the MAC address is recorded in the AP memory. When the recorded MAC address becomes older than W, it is removed from the AP memory and $u(t)$ decreases by one. Thus, $u(t)$ and $d(t)$ represent the active number of STAs in uplink and downlink for a period W, respectively. The AP updates the required utilisation ratio such that

$$\psi(t) = \frac{d(t)}{u(t)} \qquad (2)$$

Although this implementation of ψ does not exactly reflect the actual offered load to the WLAN, it is easily implemented in the AP and the feedback information from STAs is not required. Moreover the proposed method does not require the modification of the IEEE 802.11 standard, which makes it compatible with the deployed STAs.

Results: The values of parameters for the simulation runs are based on the IEEE 802.11b direct sequence spread spectrum (DSSS) standard. The Ricean fading channel model and 1 Mbit/s channel bit rate are adopted. The destinations of data frames generated from STAs are the AP while the destinations of data frames transmitted from the AP are uniformly distributed among STAs. The data frames are generated with the exponential distribution in which the arrival rate is 2.5 frames/s and the data frame size is 1024 bytes.

Fig. 1 shows the utilisations of downlink and uplink traffics for a fixed value of $\psi = 2$. The utilisations are normalised to the total simulation time. For the DCF, most utilisation is used for the uplink traffic which results in severe unfairness between the uplink and the downlink. Thus AP cannot transmit enough traffic in the DCF. For the proposed method, the utilisation of the downlink is twice that of the uplink because ψ is set to two. This sharing is kept constant while the number of STAs increases. Before the utilisation saturation of the proposed method, i.e. the number of STAs is less than 15, the uplink utilisation of the two methods are the same while the downlink utilisation of the proposed method is much higher than that of the DCF. Note that the system utilisation of the proposed method is higher than that of the DCF. This is because the AP in the proposed method can transmit data frames without collision whenever the utilisation ratio is less than ψ.

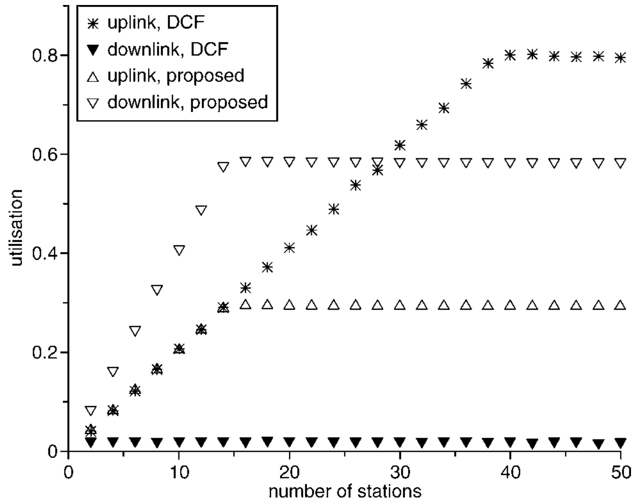

Fig. 1 *Uplink and downlink utilisation of DCF and proposed method against number of stations for $\psi = 2$*

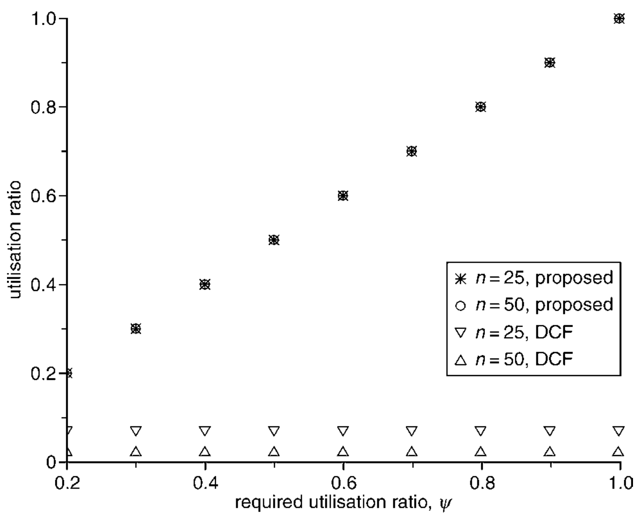

Fig. 2 *Utilsation ratio of DCF and proposed method against ψ for 25 and 50 stations*

Fig. 2 shows the utilisation ratio of the proposed method against ψ where n represents the number of STAs. The utilisation ratio of the DCF depends on the number of STAs and decreases as the number of STAs increases. The utilisation ratio of the proposed method is controlled by ψ and is independent of the number of STAs. Thus networks operators can manage the utilisation uplink and downlink by assigning a proper value of ψ.

The proposed method also supports the dynamic update for ψ. Fig. 3 shows the utilisation ratio of the proposed method when ψ is updated according to the number of MAC addresses of uplink and downlink, where n_u and n_d represent the average number of active traffic flows that have different MAC addresses in uplink and downlink, respectively. Note that n_u is set to 20 and the ideal utilisation ratios for $n_d = 10$, $n_d = 20$, and $n_d = 40$ are 0.5, 1 and 2, respectively. The utilisation ratios for the smaller values of W are larger than the ideal values. This is because the lack of information about the number of active flows gives higher priority to the downlink utilisation. It is also shown that W should be increased as the downlink traffic load increases to achieve the ideal utilisation ratio.

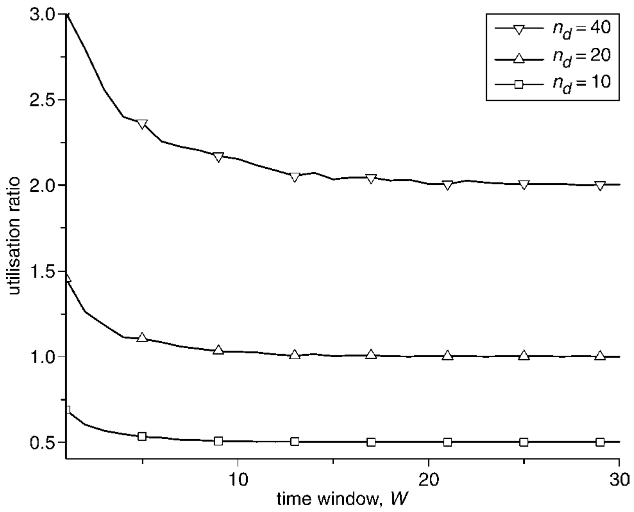

Fig. 3 *Utilisation ratio of proposed method against time window*

Conclusions: We propose an implementation method to control the utilisation ratio between uplink and downlink traffic. The utilisation ratio can be controlled by a fixed value or by a dynamic update method according to an offered traffic load. This method is validated by simulation results. The results show that the proposed method enhances the system utilisation by reducing the collision. The proposed method allocates the utilisation between the uplink and the downlink according to the required value. Thus the proposed method can be used at hotspots for the next generation cellular mobile networks.

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