Multi-AP Cooperative Diversity for Disaster-resilient Wireless LAN

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Abstract— **Orthogonal frequency division multiplexing (OFDM) based IEEE802.11 WLAN is spread widely. In the disaster situation, communication failure occurs in some areas where access points (APs) are seriously damaged and/or power lines/backhaul cables are cutoff. OFDM enables the single-frequency network (SFN) and thus, a group of surviving APs can cooperate to cover damaged AP's area. A group of surviving APs performs space-time coded cooperative diversity using the SFN nature to continuously support users in the area of damaged AP. The SFN area size can be flexibly controlled by changing the number of cooperating APs according to the damaged area size. In this paper, the operational principle of space-time coded multi-AP cooperative diversity is presented.**

Keywords-Disaster-resilient networks, cooperative diversity, SFN, frequency-domain equalization

I. Introduction

The Great East Japan Earthquake on 11 March 2011 [1] seriously damaged communications networks in very wide areas along the Pacific coastline. This damage disrupted smooth transfers of safety check and aid supply information. For countries like Japan, development of disaster-resilient communications network is quite important and urgent.

Immediately after the Great East Japan Earthquake, we started an R&D project to develop a disaster-resilient multi-layered communications network. The multilayered communications network immediately reconfigures the surviving resources of different types of network (e.g., cellular, WLAN, WiMAX, adhoc network, satellite network, etc) to detour the traffic in a damaged network. One of the promising element networks other than cellular network is widely spread orthogonal frequency division multiplexing (OFDM) based WLAN [2]. In the disaster-stricken areas, many WLAN access points (APs) may be damaged. However, by exploiting OFDM's nature, a group of surviving APs surrounding a damaged AP can form the single frequency network (SFN) [3] to cooperatively support the users in a damaged AP area.

In this paper, we will present space-time coded multi-AP cooperate diversity for a disaster-resilient WLAN.

II. Multiple AP cooperative Diversity

Right after the disaster, serious traffic congestion would occur as a fairly large volume of communication traffic which requires urgent transfer is generated for safety confirmation of relatives or colleagues, etc. However, it is worth noting that the dominant of the traffic is the short message type traffic. Currently, WLAN APs operate independently and therefore, some *outage areas* may be created due to damaged APs, where no communications opportunity is provided or communications quality is seriously degraded. Although this situation can be allowed during the normal situation, it should be prevented in case of disaster.

A. SFN and cooperative diversity

In the disaster situation, some APs may be damaged and communications in the areas covered by damaged APs are disconnected. The outage area should be kept as narrow as possible for short message type traffic of e.g. safety confirmation while the peak data rate can be lowered. One possible solution is multi-AP cooperative diversity, which is similar to the coordinated multi-point (CoMP) transmission technology in the 3GPP long term evolution (LTE) [4, 5]. An important difference between 3GPP CoMP and multi-AP cooperative diversity is that the aim of the latter is to narrow the outage area as much as possible for low speed short message type communications at the cost of the peak data rate while the former aims at increasing the data rate near the cell edge.

For OFDM based WLAN, an arbitrary number of surviving APs can form the SFN to cover the damaged area as shown in Fig. 1. The SFN area size can be flexibly controlled by changing the number of cooperating APs. One of the cooperating APs acts as a gate-way to the core network and a signal processing center for space-time coding and decoding. OFDM allows the coarse timing synchronization among APs owing to the cyclic prefix (CP) insertion. Timing offset up to CP length is permitted among the APs in the SFN area. SFNs with different area sizes can coexist depending on the degrees of damage to WLAN and traffic congestion.

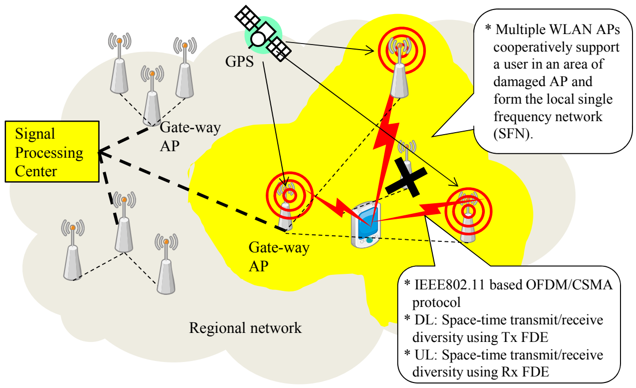

Figure 1. Multi-AP cooperative diversity.

B. *Operational principle*

The cooperating APs can be considered as spatial diversity branches. Since locations of cooperating APs are geographically separated, the adverse impacts of shadowing and path losses can be mitigated as well as the multipath fading. An important property of multi-AP cooperative diversity is that the SFN of different area size can be formed flexibly. Space-time block coded joint transmit/receive diversity (STBC-JTRD) [6] and simple Alamouti's space-time coded transmit diversity (STTD) [7] can be applied to the downlink and uplink transmissions, respectively. The former (the latter) allows an arbitrary number of transmit (receive) antennas while keeping the same coding rate. In STBC-JTRD, terminals can be equipped with as many as 6 antennas. The space-time coded multi-AP cooperative diversity can be used not only during the disaster situation, but also during the normal situation to improve the communication quality.

III. Preliminary Simulation Reaults

A simple one-dimensional network model consisting of three APs, each equipped with single transmit antenna, is considered. OFDM with N_c=64 subcarriers, CP of N_g=16-length, and QPSK data modulation is considered. The center AP is assumed to be damaged. Two neighbor APs form the SFN and perform two-AP cooperative diversity to support a user terminal with N_{user}=2 receive antennas in the damaged AP area. The path loss exponent of 3.5 and the log-normal shadowing loss of standard deviation of 7dB are assumed. A frequency-selective fading channel having 16-path uniform power delay profile is assumed. The normalized transmit E_s/N_0 is set to 12dB (which gives the received E_s/N_0=12dB at the center between two adjacent APs).

The simulated 10% and 90 % outage throughputs of the downlink achieved by two-AP cooperative diversity are plotted in Fig. 2 as a function of the user location between two surviving APs (note: the distance between two adjacent APs is normalized to one and hence, the distance between two surviving APs is two). It can be seen from the figure that the 10% outage throughput is improved compared to the case when the user in the damaged AP area accesses one of the neighbor APs. Also seen is that the 90% outage throughput is kept the same at all places between two surviving APs.

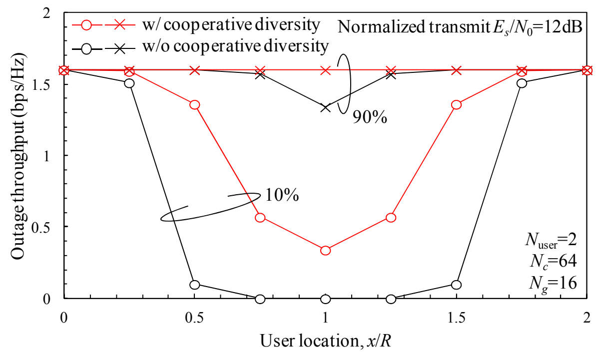

Figure 2. Throughput distribution.

IV. Conculusion

This paper introduced space-time coded multi-AP cooperative diversity for OFDM based WLAN. By changing the number of cooperating APs according to the damaged area size, the SFN can be flexibly formed. The operational principle of the multi-AP cooperative diversity was presented. The use of STBC-JTRD (STTD) for downlink (uplink) enables the flexible formation of the SFN. Preliminary simulation results were presented by assuming a simple one-dimensional network model consisting of three APs. Capability of multi-AP cooperative diversity was discussed in the single-user environment. The multi-AP cooperative diversity in a multi-user two-dimensional network case is left as our future study.

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