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Performance Evaluation of 2×2 Switched Beam Antennas with Null Locating for Wireless Mesh Networks

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***Abstract*—A concept of switched beam antennas consisting of 2×2 rectangular array spaced by λ/4 accompanied with a null locating has been proposed in the previous work. In this letter, the performance evaluations of its prototype are presented. The benefits of using proposed system have been clearly measured in term of signal quality, throughput and delays. Also, the impact of position shift which mesh router is not located on the expected beam direction has also been investigated.

***Keywords*—Antenna array, Beamforming, Null steering, WMNs.

I. Introduction

RECENTLY, Wireless Local Area Networks (WLANs) [1] have become an infrastructure in every building. The connection or communication between users and network is accomplished through an access point. In WLANs, access points communicate to each other using cables. This causes an expense and somehow introduces difficulty in accessibility for some areas. To tackle these impairments, the idea of exploiting radio signal instead of cables has been recently proposed, so called Wireless Mesh Networks (WMNs) [2]. These networks are constituted by radio nodes organized in a mesh topology. Once one node can no longer operate, the rest can communicate to each other directly or through one or more intermediate nodes. To this end, a draft extension of the IEEE 802.11 standard for WMNs is under development [3].

As radio signal is utilized in WMNs, co-channel interference remains a limiting factor which the system designers have to concern. To deal with this impairment, lot of attention in the area of WMNs has been paid to smart antenna technologies. These techniques rely on beamforming algorithm to provide maximum gain at a desired direction and steer nulls or sidelobes to undesired directions. The key success of smart antennas is an antenna array and a suitable signal processing unit. Fully adaptive smart antennas are able to perform the electrical beam and null steering [4]. These capabilities come with a high level of computational for signal processing unit, resulting in high expense and complexity. On the other hand, switched-beam antennas being one typical type of smart antennas do not need additional cost and complications. In these systems [5], a number of predefined beams are formed in different directions by antenna array and beamforming network. However, switched-beam antennas have the limitation of interference suppression as it cannot control nulls' directions. Although, this problem can be avoided when utilizing fully adaptive smart antennas, its complexity makes the concept impractical for WMNs. In [6], the authors proposed a low profile beamformer with null locating capability for WMNs. This beamformer provides multi-beam patterns simultaneously around the router of interest. In addition, interference signals can be cancelled with a straightforward null-steering method described in the paper. However, the true evaluation of the proposed concept had never been reported. In this letter, the performance evaluation of switched beam antennas with null locating for WMNs is presented. The prototype is constructed and tested under IEEE 802.11 a/b/g infrastructure. The performances in term of signal quality, throughput and delays are investigated. Sometimes it is impossible to locate mesh router on the beam direction of desired node. Hence, also in the letter, the effect of position shift which mesh router is not located on the expected beam direction has also been examined.

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II. Beamforming Concept in WMNs

Fig. 1 presents WMNs in different scenarios in term of air interface. Note that this paper focuses on the mesh routers, not mesh clients. This is because positions of mesh routers are relatively stable and evenly distributed within the network. The Concept of WMNs has been initialized with omni-directional radiation, as shown in Fig. 1a. As we can see, interference signals from neighboring routers become interferers, as strong as signal strength from the router of interest. This introduces an increase in blocking probability. According to this, the works presented in [2] and [7] have proposed to adopt the concept of using switched-beam systems and directional antenna, respectively, for WMNs. As shown in Fig. 1b, an antenna array is utilized at mesh routers

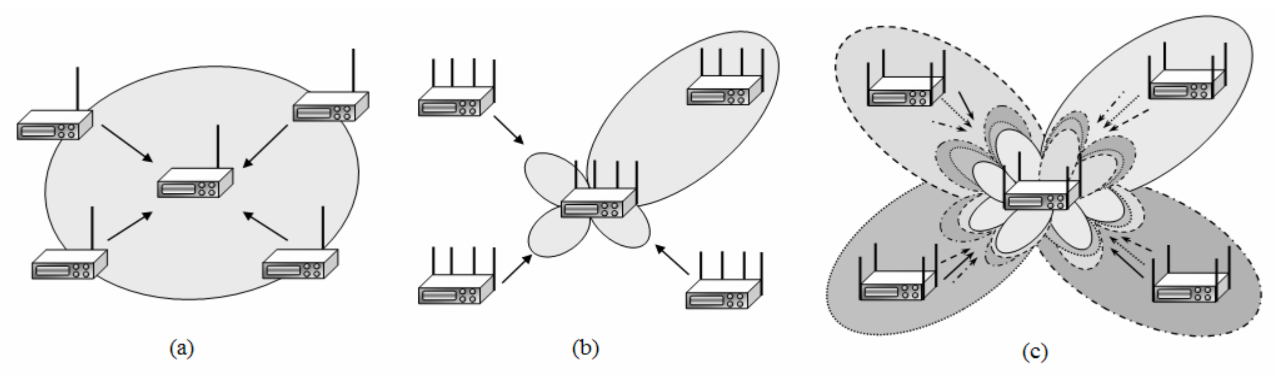

Fig. 1 Configuration of WMNs employing different antenna systems, (a) omni-directional antenna (b) directional antennas (c) proposed antenna systems.

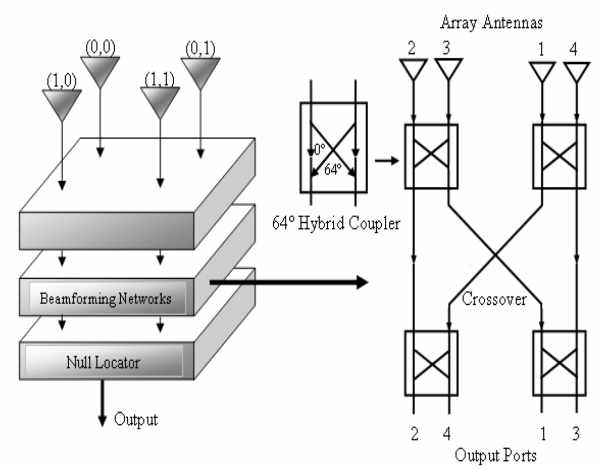

Fig. 2 Configuration of beamforming networks.

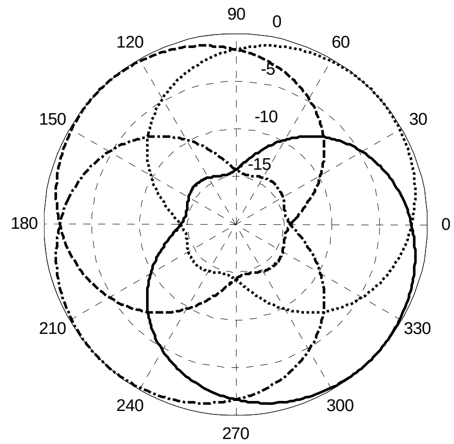

Fig. 3 Simulated radiation patterns of beamformer in [8] at 2.45 GHz.

to provide directive gain in the desired direction. The energy saving can be achieved with this concept. However, interference signals remains in the system and their amount is relatively large for the array having high sidelobe levels. This can be decreased by utilizing a large number of antenna elements, resulting in high expense. So, controllable null locating is attractive when employing a small number of antenna elements in order to meet the requirement of low profile systems. Fig. 1c demonstrates the concept of air interface proposing in this paper. As we can see, multiple beam patterns are designable and simultaneously produced in any given directions with a low compact size array in cooperating with a suitable beamforming network. In each beam pattern, nulls' locations can be produced in the directions of undesired signals. The detail of each part is described as follows**.**

III. Low Profile Beamformer for WMNs

The beamformer consists of 2×2 rectangular array and beamforming network as shown in Fig. 2. The choice of 2×2 array configuration is due to the requirement of a minimum number of antenna elements which is able to take responsibility for signals coming from 0 to 360° around the array. The array is spaced by λ/4 as shown in this Fig.. The received signals are delivered to beamforming network in order to accomplish beam formation in predefined directions, simultaneously. The beamforming network presented in [8] is adopted as its simplicity. It is constituted by four 64°-hybrid couplers and a crossover. Note that the mentioned beamforming network provides main beam directions at 45°, 135°, 225° and 315° simultaneously. Afterwards, the four outputs, from four beams, are conveyed to null locator as shown in Fig. 3, which is detailed in next section.

IV. Null Locating Method

Nowadays, lots of effective null steering algorithms e.g., [9]-[10] can be found in literatures. Unfortunately, those methods require high level of computation which can be handled by expensive signal processor. This is not attractive for WMNs application [11]-[12]. Therefore, this paper presents a straightforward null locating method which requires only multiplying some suitable coefficients at the output signals from beamforming network. The procedure to calculate the mentioned coefficients is described in [6] which will not be repeated here.

In the circumstance of WMNs, the directions of those signals coming from mesh routers are fixed. However, the directions of signals in other wireless systems can be easily found using some straightforward algorithms available in literatures [13]-[15].

V. Experimental Results

To confirm the beamforming capability of the proposed concept, a prototype of the beamformer is constructed, which is constituted by three major parts: array antennas, beamforming network and null locating network. For the array antennas, 4 standard monopole antennas are employed in which it provides gain of 5 dBi individually. The array is arranged in 2×2 lattice. The array spacing is quarter-wavelength at 2.45 GHz. The prototype of null locating networks are constructed and tested. The directions of interest are given at 45°, 135°, 225°, 315°. If one direction is chosen to be desired direction, the rest directions become interference directions.

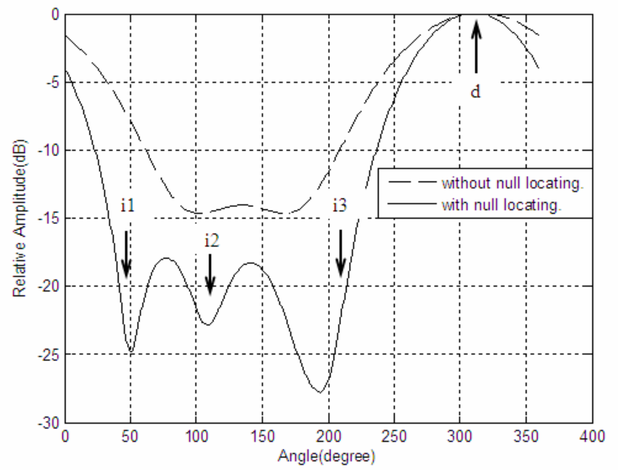

Fig. 4 Radiation pattern of a 2×2-beamformer when the desired signal is coming from 315° and interference signals are coming from 45°, 135° and 225°.

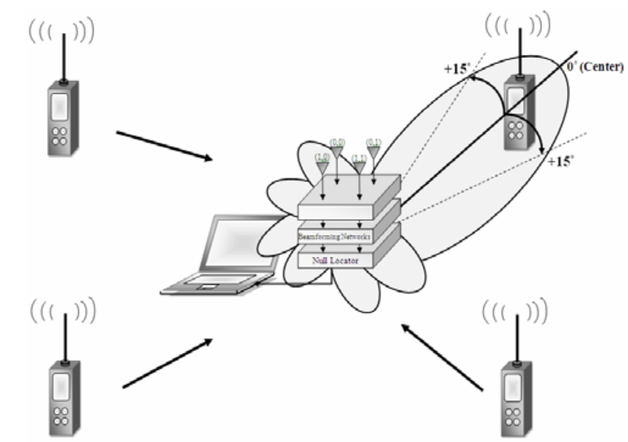

Fig. 5 Test scenarios on location shift of mesh router.

The performance of constructed prototype is measured and one of four configurations shown in Fig. 4 whereas dash line represents radiation pattern of the array without null locating and solid line indicates the one when including null locating.

To validate the use of proposed system for WMNs, the measurement is required to be undertaken. The basic configuration of WMNs is illustrated in Fig. 5. In this Fig., five nodes as mesh routers are employed and the proposed switched beam is implemented at the center node. As non solid standard for WMNs, one approach of air interface is able to be arranged by using conventional IEEE 802.11 a/b/g. In this paper, four WLAN access points are located at the corner of Fig. 5. For proposed switched beam, the illustration of measurement setup at the center node is depicted in Fig. 6. To measure signal strength, there is no compensation due to all power loss caused by connectors, transmission lines and combiner. Hence, it makes sure that the proposed system is practically tested for real application and promptly used for WMNs as its presented form. Fig. 7 and 8 presents the received signal strength versus power transmission for conventional omni-directional antenna and proposed switched beam antennas.

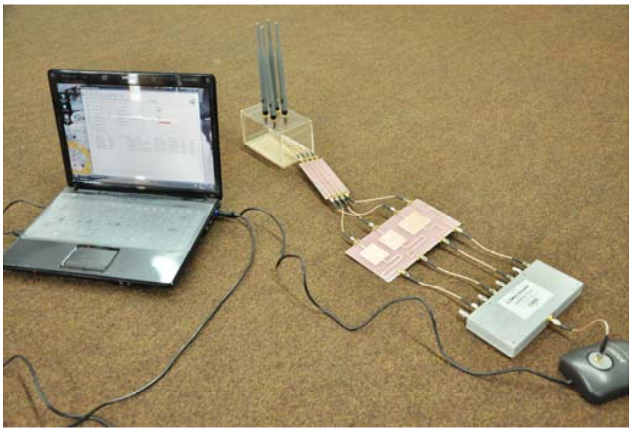

Fig. 6 Measurement setup of proposed system for WMN.

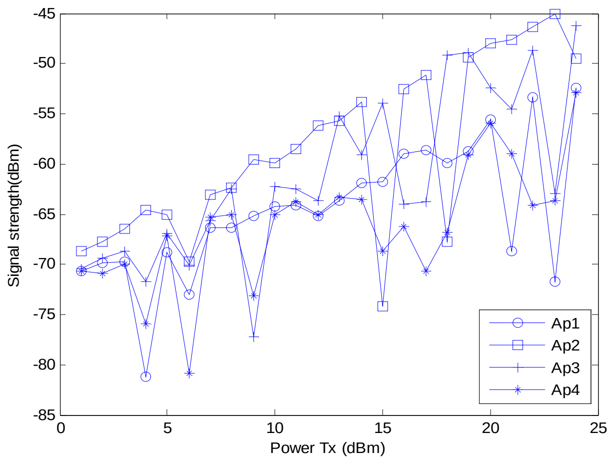

Fig. 7 Received signal strengths from four access points by using conventional omni-directional antenna.

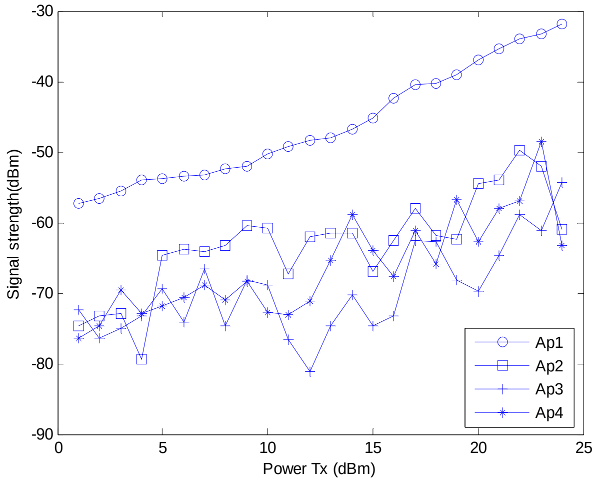

Fig. 8 Received signal strengths from four access points by using switched beam with null locating networks.

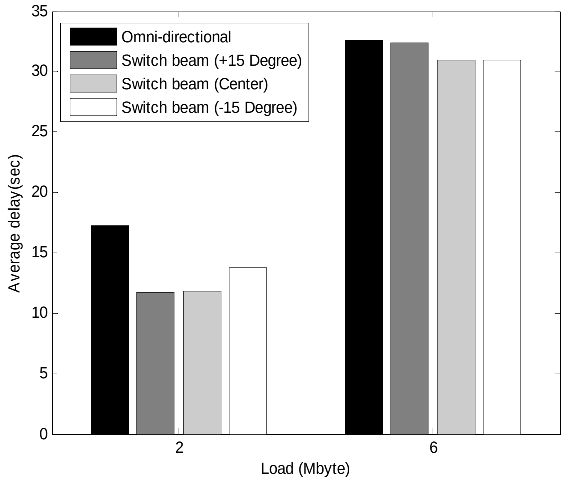

Fig. 10 Average delay when downloading data for conventional omni-directional antenna and proposed switched beam antennas.

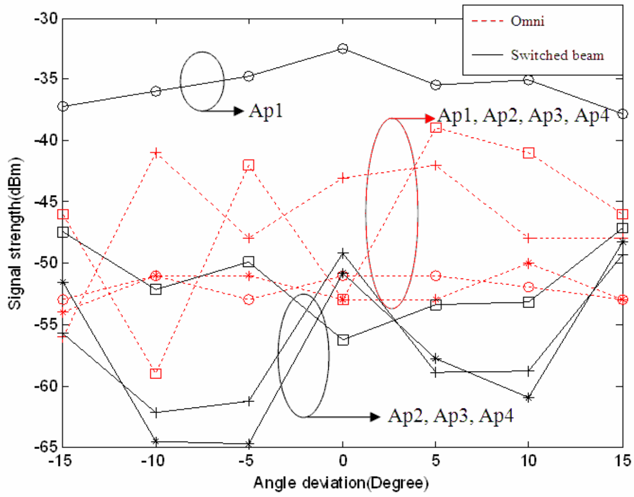

Fig. 9 Received signal strengths vs. angle deviation for four access points by using conventional omni-directional and proposed switched beam antennas.

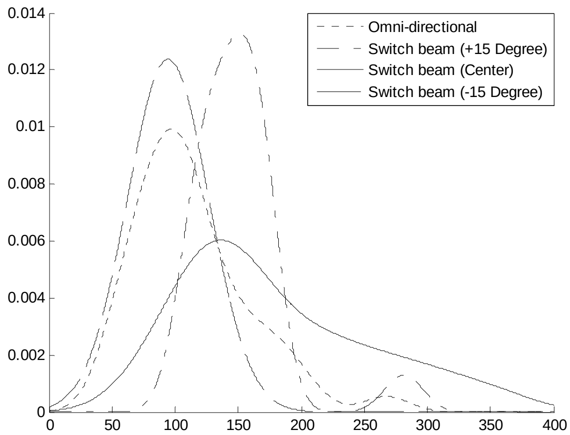

Fig. 11 Probability density function of measured throughput when using conventional omni-directional antenna and proposed switched beam antennas.

For omni-directional antenna, every power transmittion provide the received signal strengths of four access points vary from -45 to -83 dBm and there is no dominant access point. In turn, the results of proposed switched beam antennas provide two significant groups which are the access point in desired direction, Ap1, and null directions, Ap2 to Ap4. The gap between signal strength of desired access point and the others is ranged from 10 to 17 dB. These results confirm the use of proposed switched beam to enhance signal quality as well as suppress interference signals.

In practice, the position of mesh router is not always on beam direction. Therefore, the following measurements based on configuration in Fig. 5 are undertaken to investigate whether proposed system can provide benefits or not if mesh location is shifted from beam direction. Fig. 9 presents the received signal strength versus angles deviation for omni-directional antenna and proposed switched beam antenna. We can see that a while angle is deviated +15° and -15° switched beam antenna still provided a received signal strength of desired access point better than omni-directional antenna.

Fig. 10 provides the average delay versus data size when downloading. As seen in the Fig., proposed switched beam antennas can help the system to download more quickly for both 2 and 6 Mbytes. Fig. 11 presents the probability density function of throughput. In this Fig., the total 100 samples are measured and evaluated through well known website, www.numion.com. The results show that the omni-directional antenna provides lower mean throughput than switched beam antennas and the probability having throughput more than mean value of omni-directional antenna is less than switched beam antennas of all angle deviation. These results indicate the success of proposed system even the mesh router is not installed on the direction of main beam.

VI. Conclusion

This paper has presented the measurement results of low profile beamformer with null locating for WMNs. The prototype offer benefits in term of signal quality, throughput and delays. Also its benefits can be achieved even the mesh router is located by $\pm$15 degree deviating from beam direction.

Acknowledgment

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References

[1] B.P. Crow, I. Widjaja, L.G. Kim, P.T. Sakai, "IEEE 802.11 Wireless Local Area Networks", *Communications Magazine*, IEEE , vol. 35 , 1997, pp.116-126.
[2] Ian F. Akyildiz, Xudong Wang, and Weilin Wang, "Wireless Mesh Networks: A Survey", *Computer Networks and ISDN Systems* , vol. 4, 2005.
[3] F. Babich, M. Comisso and L. Mania, Multi-Antenna Techniques for "Wireless Mesh Networks in an Outdoor Environment", *Communications ICC '07 IEEE International Conference*, 2007, pp. 4961-4966.
[4] S. P. Applebaum, "Adaptive Arrays", *IEEE transaction on Antennas and Propagation*, vol 24 , pp. 585-598.
[5] W.R. Li, C.Y. Chu, K.H. Lin, S.F. Chang, "Switched-Beam Antenna Based on Modified Butler Matrix with Low Sidelobe Level", *Electronics Letters*, vol 40, 2004, pp. 290-292.
[6] S. Pradittara, P. Uthansakul, R. Wongsan and M. Uthansakul, "Null Steering Network for Low Profile 2×2 Switch Beam Antenna", *International Symposium on Antennas and Propagation,* Thailand, 20-23 October 2009.
[7] B. Raman and K. Chebrolu. "Design and Evaluation of a New MAC for Long-Distance 802.11 Mesh Networks", *In The 11th Intl. Conference on Mobile Computing and Networking (MOBICOM)*, Colongne, 2005.
[8] M. Uthansakul and P. Uthansakul, "Low Profile DOA Finder at 2.4 GHz", *Microwave and Optical Technology Letter*, to be published on January, 2009.
[9] H.M. Elkamchouchi, M.A.R.M. Adam, "A New Constrained Fast Null Steering Algorithm", *Antennas and Propagation Society International Symposium IEEE*, vol 2, 2000, pp. 926-929.
[10] H. Steyskal, R.A. Shore and R.L. Haupt, "Methods for Null Control and Their Effects on the Radiation Pattern", *IEEE Trans. Antennas and Propagation*, vol 34, 1986, pp. 404-409.
[11] J.A. Stine, "Exploiting smart antennas in wireless mesh networks using contention access", *IEEE Wireless Communications*, vol 13, 2006, pp. 38-49.
[12] V. Jain, A. Gupta, D.P. Agrawal, "On-Demand Medium Access in Multihop Wireless Networks with Multiple Beam Smart Antennas", *IEEE Transactions on Parallel and Distributed Systems*, vol 19, 2008, pp. 489 – 502.
[13] N. Sangmanee, P. Uthansakul, R. Wongsan, M. Uthansakul, "Finding capability enhancement for 360-degree DOA finder", *ECTI-CON 2009*, pp. 786 – 789.
[14] E. Boyer, A. Ferreol, P. Larzabal, "Simple robust bearing-range source's localization with curved wavefronts", *IEEE Signal Processing Letters*, vol 12, 2005, pp. 457 – 460.
[15] D. Astely, B. Ottersten, "The effects of local scattering on direction of arrival estimation with MUSIC", *IEEE Transactions on Signal Processing*, vol 47, 1999, pp. 3220 – 3234.

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