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INTERFERENCE AND TRAFFIC AWARE CHANNEL ASSIGNMENT IN WMN USING A GAME THEORETIC APPROACH

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Abstract

The Wireless Mesh Network (WMN) has already been recognized as a promising broadband access network technology from both academic and commercial perspective. In order to improve the performance of WMNs, extensive research efforts have been dedicated towards finding means to increase the number of simultaneous transmissions in the network while avoiding signal interference among radios. In case of WMNs based on IEEE 802.11 b/g standards, most recent research works have relied upon the usage of orthogonal channels for solving the Channel Assignment (CA) problem. In this paper, we explore the possibility of exploiting Partially Overlapped Channels (POCs) by introducing a novel game theoretic distributed CA algorithm. The proposed algorithm CoCAG is shown to achieve near-optimal performance in the average case.

I. INTRODUCTION

Wireless Mesh Networks (WMNs) have attracted tremendous interest from researchers involved in both academia and industry [1]. While a WMN consists of a multi-hop environment, its concept and target differ from those of the conventional Mobile Ad hoc Networks (MANETs). In a typical WMN, there are two types of nodes, namely Mesh Routers (MRs) and Mesh Clients (MCs). MRs is responsible for network routing and bridging while MCs are light-weight nodes performing simple client functions. One key feature of the WMN is the backbone network composed by MRs in which they are usually static and have no constraints on energy consumption. Due to these attractive features, WMNs are expected to appear as a promising technology in the Next Generation Networks (NGNs) in order to deploy ubiquitous Internet access. To promote this phenomenal prospect, a number of standards have already been developed for WMNs for different access ranges, namely IEEE 802.15.4, IEEE 802.11s and IEEE 802.16j [1]. Since IEEE 802.11 is one of the most popular access technologies for commercial end-users, we are interested in WMNs based on this technology. One of the most promising techniques in Multi-Radio Multi-Channel (MRMC) field is Partially Overlapped Channel Assignment by using IEEE 802.11 b/g technology, which can increase the network throughput by exploiting more simultaneous transmissions. According to this standard, there are eleven channels available for communication on the 2.4 GHz band. By exploiting all eleven channels in a systematic approach to avoid the interference among adjacent channels, we can achieve a higher number of simultaneous transmissions than restricting ourselves with the use of only three orthogonal channels. Note that this approach is not as straightforward as it seems at the first glance. Unless it is carefully planned, adjacent channel interference may become significant in severely degrading network performance instead of improving it. In this paper, we use game theory to design a systematic approach to utilize partially overlapped channels in WMNs while minimizing the adverse effect of adjacent channel interference. Game theory is a mathematical tool, particularly useful, in the network engineering field to model highly complex scenarios that may include complex traffic models, mobility, unpredictable link quality, and so forth, in which pure mathematical analysis has met limited success. This mathematical tool provides researchers with the ability to model individual or independent decision makers called “players”. Every player interacts with other players and has an impact on their decisions. The dynamics of WMNs and MANETs closely resemble to this observation.

A channel assignment A assigns a set A(u) of channels (jA(u)j 6 k(u)) to each node u 2 V . Thus, A induces a new graph model G = (V;E) where two nodes u and v are connected if u ! v 2 EI and they share at least one common channel. In case u and v share multiple channels, the set E may include as many links between the two nodes as the number of common channels. channel assignment that satisfies such condition exists (decision problem) is an NP complete problem. Given that it is not possible (in polynomial time) to determine whether a channel assignment exists that makes a given set of pre-computed flow rates schedulable, proposed heuristics, in the attempt to keep the total utilization of every collision domain below 1, seek a solution that minimizes the maximum total utilization of all the collision domains. Such a problem turns out to be the optimization version of the decision problem stated above and hence it is NP-complete, too. Consequently, channel assignment algorithms are mainly heuristics that attempt to minimize max e2E Utot(e).The channel re-assignment problem: The problem we intend to tackle is to re-assign at most a given number of channels in order to cope with variations in the set of pre-computed flow rates. Our proposed solution thus assumes the availability of a solution to the channel assignment problem given an original set of pre-computed flow rates.

Wireless ad hoc network is characterized by a distributed, dynamic, self-organizing architecture. Each node in the network is capable of independently adapting its operation based on the current environment according to predetermined algorithms and protocols. Analytical models to evaluate the performance of ad hoc networks have been scarce due to the distributed and dynamic nature of such networks. Game theory offers a suite of tools that may be used effectively in modeling the interaction among independent nodes in an ad hoc network. In this article we describe how such games can be set up and discuss recent advances in this area.

II. LITERATURE REVIEW

In 2010, the work conducted by Zhou *et al.* developed fully distributed scheduling schemes, which solve the following three problems for video streaming over multi-channel multiradio networks: (*i*) CA, (*ii*) rate allocation, and (*iii*) routing and fairness. Instead of focusing on optimal system throughput or scheduling efficiency as with conventional scheduling schemes, this work aimed at achieving minimal video distortion and a level of fairness through integrated media aware distribution and network resource allocation. This work, however, did not consider the issue of overlapping or non overlapping channels in formulating the CA problem.

Skalli *et al.* [2] reviews a number of CA schemes using non-overlapping channels. According to this survey, "this (i.e., the use of non overlapping channels) leads to efficient spectrum utilization and increases the actual bandwidth available to the network".

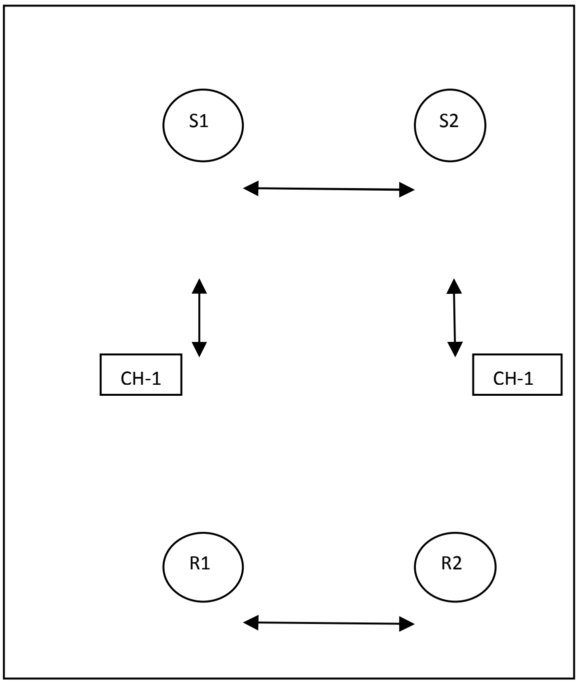
Bukkapatanam *et al.* [3] using numerical analysis demonstrates that the usage of overlapping channels achieves better performance than three no overlapping channels for the backbone network, expanding the previous work of Mishra [4], [5]. However, none of the these works clearly delineates a novel CA algorithm exploiting POC. Following the promising trend of using POC, a new heuristic CA algorithm was proposed in [6] and in one of our earlier works [7]. In this paper, we further develop our previous work in [7] by addressing the WMN channel assignment problem from the game theoretical perspective in contrast with a heuristic approach adopted earlier. Game theory has been utilized effectively in wide areas of research, particularly in formulating and solving Economics problems. Using the game theoretical perspective to address complex engineering issues has immensely attracted the attention of prominent researchers in the last decade and its applicability has been abound ever since. More specifically in the context of network communications, there has been a plethora of game theory based work, ranging from power control in cellular radio systems [8] to optimal routing control [9] [10], network congestion [11] Readers unfamiliar with Game Theory concepts and its applications are encouraged to study the work in [12], which contains fundamental results in this area and are specially focused on communication applications.

Meshkati *et al.* [13], who proposed a non cooperative game theoretic framework, which aims at performing trade-offs among energy efficiency, delay, throughput, and constellation size. This work shows that a user, in order to maximize its utility in terms of energy efficiency, needs to select the lowest modulation level, which can accommodate the user's Quality of Service (QoS) delay constraint. However, this approach missed one important aspect, i.e., it did not take the CA problem into account. The work in [14] developed a game-theoretic model for radio resource management in a network architecture, which combines IEEE 802.11 Wireless Local Area Networks (WLANs) with IEEE 802.16-based multi-hop wireless mesh infrastructure for relaying the WLAN traffic to the Internet. The formulated game offers the players fair bandwidth allocation and optimal admission control of different types of connections such as WLAN connections and relay connections in an IEEE 802.16 mesh router. In [15], an incompletely cooperative game theory was proposed to improve the system performance of WMNs. In this approach, all the players contend for the channel to transmit real packets always with the optimal strategy. [16] offers game theory models to address the CA problem in wireless networks. The afore-mentioned game theoretic approaches, however, do not consider exploiting partially overlapped channels in wireless networks, particularly in WMNs. They addressed the problem by varying the channel width in order to achieve a fair/optimal resource allocation. In this paper, we employ game theory concepts to model MRs as decision makers of a cooperative game. The interaction among all MRs can be classified as an *identical interest game* as in [17]. Furthermore, we introduce a negotiation based CA algorithm that converges to a steady state, in other words a Nash Equilibrium (NE), and as a property of identical interest games, this condition implies achieving an optimum CA.

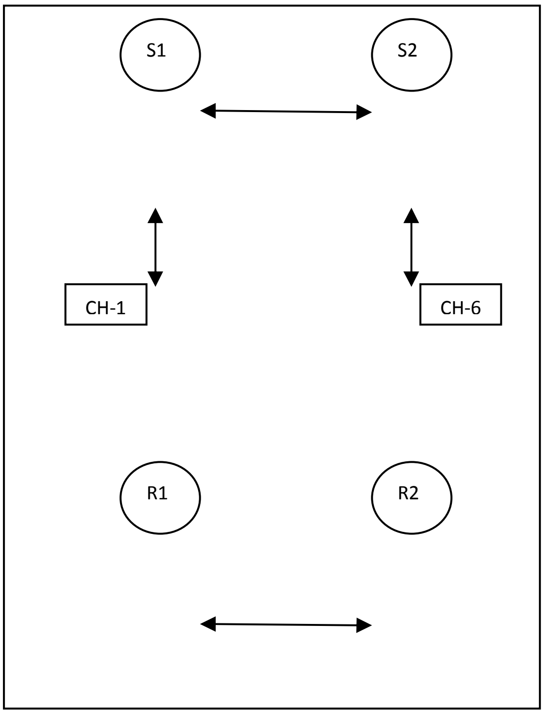
III. SYSTEM MODEL

The CA issue defined as an optimization problem in terms of mapping available communication channels to network interfaces in order to maximize the communication capacity while minimizing signal interference. Note that Interference range is defined as the distance within which interference occurs. In a multi-channel environment, four different types of interference and their influence on the network capacity should be addressed. To describe easily, let us consider two pairs of nodes where each pair has a sender and a receiver. Let the sender and receiver of the first pair be $S1$ and $R1$, respectively. The sender and receiver of the second pair are denoted by $S2$ and $R2$, respectively. To illustrate our considered system model, first we describe the following terms.

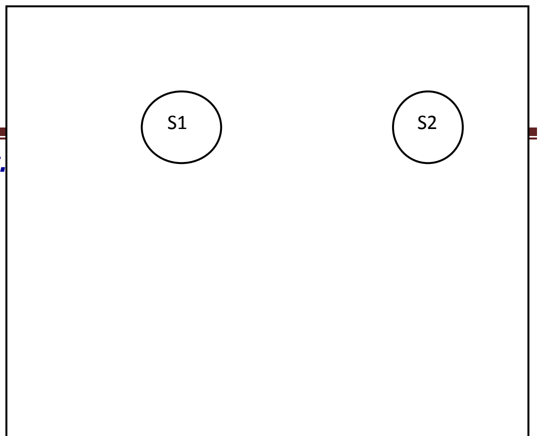
- **Co-channel Interference:** Co-channel interference occurs in case that all four nodes involved in the afore-mentioned pairs are operating in the same channel. Because of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), this type of interference is less harmful for the network capacity than Adjacent Channel Interference. Consider the following scenario: node $S1$ is starting to transmit a packet to $R1$. $S1$ checks if the medium is busy or idle. If it detects that the medium is busy, the node will withdraw its attempt to transmit by postponing it. However, if the medium is idle, it will proceed with the transmission. While $S1$ is sending data to $R1$, consider a scenario in which $S2$ also attempts to send a packet to $R2$. $S2$ will detect the busy medium. Hence, $S2$ will withdraw the transmission attempt and wait over a back off period. Later on, it will attempt again and if the transmission between *S*1-*R*1 is already finished, *S*2 will finally succeed with the signal transmission to *R*2. In this scenario, we have a contention based access.

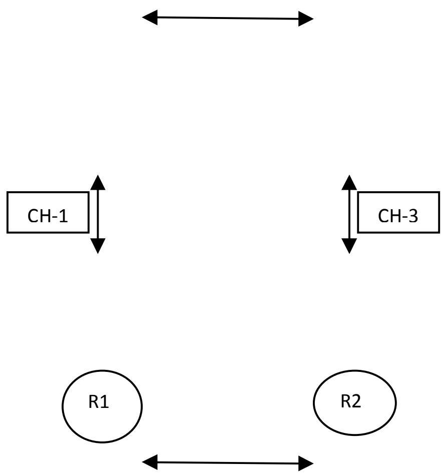


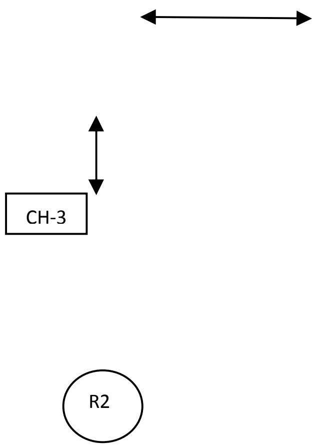
• **Orthogonal Channels:** Consider another scenario whereby *S*1-*R*1 and *S*2-*R*2 are using two orthogonal channels. Again, *S*1 detects an idle medium and starts the packet transmission. Meanwhile, *S*2 will also detect an idle medium since it is operating on a distinct channel. Both pairs are able to successfully transmit their packets simultaneously, because there is no overlapping frequency band between those channels. Limitation of this approach is that only three pairs of nodes can communicate in this manner since only three out of the eleven available channels, namely channels 1, 6, and 11, are orthogonal.



• **Adjacent Channel Interference**: This kind of interference seriously degrades the network capacity. Here, we consider *S*1-*R*1 and *S*2-*R*2 assigned to channels 1 and 3, respectively. *S*1 begins transmitting first, *S*2 will detect an idle medium in







channel 3 and also starts to send its packet. However, since channels 1 and 3 share a common frequency band, the receivers may not be able to successfully decode the packets, causing a transmission error that severely degrades the network throughput.

- **Self Interference**: Self-interference is defined as a node causing interference to one of its own transmissions. This case will occur in multiple radio nodes using omni directional antennas.

Considering the afore-mentioned types of interference, the authors in [6] developed a schematic procedure for CA. This model is called as I-Matrix and it determines whether it is possible or not to assign channels to a given link exploiting POC. To adopt this model, we need to define four key components, namely Interference Factor, Interference Vector, Interference Matrix, and finally Threshold Interference.

A. Interference Factor

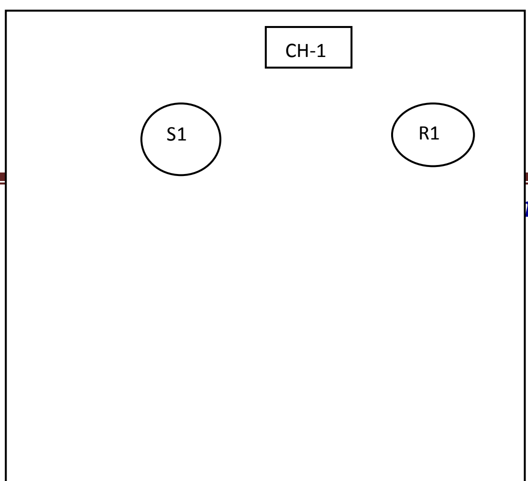


TABLE I: Interference Range (IR)

δ	0	1	2	3	4	5
$IR(\delta)$	13.26	9.08	7.59	4.69	3.21	0

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The *interference factor* $f_{i,j}$ takes as input parameters geographical distance and channel separation, and provides the effective spectral overlapping level between channels i and j. In order to calculate $f_{i,j}$, the experimental measurements showed in [21] [22] are used. To achieve an environment as similar as possible to the previous CA scheme, we use the same *Interference Range* (IR) table where δ is the channel separation $\delta = |i - j|$ and $IR(\delta)$ is the maximum distance in which there will be interference between channels i and j. Given the IR table, let d be the Euclidean distance between transceivers using channels i and j. Also, if transceivers are in the same node, we define d being zero. To calculate $f_{i,j}$ we should consider the following three cases:

(1) $f_{i,j} = 0$: when $\delta > 5$ or $d > IR(\delta)$

In this case, there will be no interference between the radios since either they are assigned orthogonal channels,

Or they are distant enough not to cause interference given IR for channels i and j.

(2) $1 < f_{i,j} < \infty$: when $0 \le \delta \le 5$ and $d \le IR(\delta)$

Here, we have two radios assigned to overlapping channels i and j, also the distance between them is within the interference range. Thus, interference factor should be calculated as the following equation in which $f_{i,j}$ is inversely proportional to the distance between radios.

$f_{i,j} = IR(\delta)/d$: (1)

(3) $f_{i,j} = \infty$: when $0 \le \delta \le 5$ and $d = 0$

Here, we strictly exclude the self-interference to occur. Overlapping channels will not be assigned at a given node.

B. Interference Vector

For a given channel *i*, we should calculate the Interference Factor between this channel and all other 11 channels. Note that here, the distance *di* stands for the closest radio at channel *i*. In order to permit the co-channel assignment, we add Co channel (*CoC*) column in the I-Matrix. This value will be set to one, if the channel assigned to that radio is an interfering co-channel, or to zero, otherwise.

C. Interference Matrix

After combining the interference vectors for all 11 channels. Each node has its own I-Matrix. Initially, all entries are set to zero and after a channel is assigned for any given link, every node updates its I-Matrix.

D. Threshold Interference

Setting this parameter on a value (*Th* < 1), only non interfering channels will be assigned. The tolerance for interfering links can be increased specifying (*Th* > 1). Increasing this parameter's value would lead to a more connected network. However those links would suffer with ACI. In our algorithm, we increase the network connectivity exploiting the links that cause co-channel interference.

IV. PROPOSED SOLUTION BASED ON GAME THEORY

In this section, we model our MRs as "players". The main objective of such modeling is to derive an optimal CA using the mathematical analyses provided by the Game Theory framework, and then compare this result against existing heuristic algorithms.

Each MR is considered as a *decision maker* of the game, and we model the interactions among them as a Cooperative Channel Assignment Game (CoCAG). The game is composed of a finite set of players, denoted by **A** = $\{a_1, a_2 \ldots a_N\}$ and all the players have a common strategy space **S** = $\mathbf{S}_i, \forall i$. In this context, we map the channel(s) assigned to a given MR's radios to its chosen strategy. Formally, the strategy of the *ith* player is $\mathbf{s}_i = \{ki,1, \ldots, ki,c, \ldots, ki,|C|\}$, where $|C|$ is the number of channels for the channel set **C** and *ki,c* is a binary value. *ki,c* is set to one, if channel *c* is assigned to one of the player's radio. Otherwise, *ki,c* is set to zero. The game profile is defined as the Cartesian product of the players' strategy vector, $\boldsymbol{\Psi} = \times_{i \in A} \mathbf{s}_i = \mathbf{s}_1 \times \mathbf{s}_2 \times \cdot \quad \cdot \quad \cdot \times \mathbf{s}_N$. Note that a game profile includes one strategy for each player. Also, $\mathbf{s}_{-i}$ is specially defined as the strategy set chosen by all other players except player *i*.

V. ALGORITHM

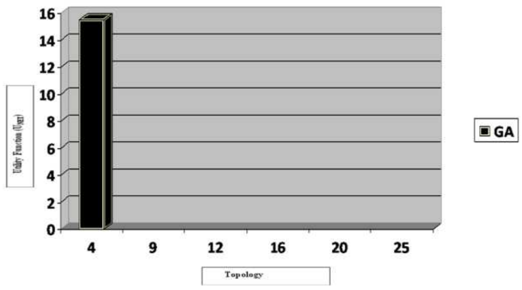
Cooperative Channel Assignment Game (CoCAG)

$s_i = \{0\} \forall a_i \in A$
while T = 0 do
  Randomly select a_i with prob. $1/N$
  $s_i^{rand} \leftarrow$ random strategy {ki, 1, . . . , ki,c, . . . , ki,|C|}
  while $s_i^{rand} \neq$ valid strategy do
    $s_i^{rand} \leftarrow$ random strategy
  end while
  if $p(s_i^{rand}, s_i^t) \geq$ random number [0, 1] then
    $s_i^{t+1} \leftarrow s_i^{rand}$
  else
    $s_i^{t+1} \leftarrow s_i^t$
  end if
  Broadcast $_{ai}$ ID + s_i^{t+1}

SIMULATION SETTINGS

Simulator	Numerical simulation using JAVA
Number of Nodes	4,9,16,20,25
Node distance	120 m
Number of radios	2
MAC Protocol	IEEE 802.11g
Data Rate	6 Mbps
Channels (2.4 GHz)	1 – 11

VII.RESULT



VI. CONCLUSION

This paper, to solve the channel assignment problem, we envisioned a novel distributed channel assignment algorithm for Wireless Mesh Networks by exploiting partially overlapped channels from a game theoretical approach, which reaches an optimal performance. Such improvements can be measured as network throughput, channel spatial re-use, and non interfering links.

REFERENCES

1. I. Akyildiz and X. Wang, "A survey on wireless mesh networks," *IEEE Commun. Mag.*, vol. 43, no. 9, pp. S23–S30, Sep. 2005.

2. H. Skalli, S. Ghosh, S. Das, L. Lenzini, and M. Conti, "Channel assignment strategies for multiradio wireless mesh networks: Issues and solutions," *IEEE Commun. Mag.*, vol. 45, no. 11, pp. 86–95, Nov. 2007.

3. V. Bukkapatanam, A. Franklin, and C. Murthy, "Using partially overlapped channels for end-to-end flow allocation and channel assignment in wireless mesh networks," in *ICC '09: IEEE Int. Conf. on Commun.*, Dresden, Germany, Jun. 2009, pp. 1–6.

4. A. Mishra, E. Rozner, S. Banerjee, and W. Arbaugh, "Exploiting partially overlapping channels in wireless networks: turning a peril into an advantage," in *IMC '05: Proc. 5th ACM SIGCOMM Conf. on Internet Measurement*, Philadelphia, PA, 2005, pp. 29–29.

5. A. Mishra, V. Shrivastava, S. Banerjee, and W. Arbaugh, "Partially overlapped channels not considered harmful," in *SIGMETRICS '06: Proc. Joint Int. Conf. on Measurement and Modeling of Comput. Syst.*, Saint-Malo, France, Jun. 2006, pp. 63–74.

6. M. Hoque, X. Hong, and F. Afroz, "Multiple radio channel assignement utilizing partially overlapped channels," in *GLOBECOM '09: Proc. IEEE Global Telecommun. Conf.*, Honolulu, HI, Nov. 2009, pp. 1 –7.

7. P. B. F. Duarte, Z. M. Fadlullah, K. Hashimoto, and N. Kato, "Partially overlapped channel assignment on wireless mesh network backbone," in *Globecom '10: Proc. IEEE Global Commun. Conf.*, Miami, FL, Dec. 2010.

8. L. Gao, X. Wanga, Y. Xu, X. Gan, H. Yu, and A. V. Vasilakos, "A game approach for cell selection and resource allocation in heterogeneous wireless networks," in IEEE/ACM Trans. Netw., to be published.

9. R. La and V. Anantharam, "Optimal routing control: repeated game approach," *IEEE Trans. Autom. Control*, vol. 47, no. 3, pp. 437–450, Mar. 2002.

10. C. Busch, R. Kannan, A. Vasilakos, "Approximating Congestion + Dilation in Networks via 'Quality of Routing' Games", IEEE Trans. Comput. to appear, doi: 10.1109/TC.2011.145.

11. R. Kannan, C. Busch, and A. V. Vasilakos, "Optimal price of anarchy of polynomial and super-polynomial bottleneck congestion games," in *GameNets 2011 : Int. Conf. on Game Theory for Networks*, Shanghai, China, Apr. 2011.

12. F. Meshkati, A. Goldsmith, H. Poor, and S. Schwartz, "A game-theoretic approach to energy-efficient modulation in cdma networks with delay qos constraints," *IEEE Sel. Areas Commun.*, vol. 25, no. 6, pp. 1069– 1078, Aug. 2007.

13. D. Niyato and E. Hossain, "Integration of ieee 802.11 wlans with ieee 802.16-based multihop infrastructure mesh/relay networks: A game theoretic approach to radio resource management," *IEEE Network*, vol. 21, no. 3, pp. 6–14, May-Jun. 2007.

14. L. Zhao, J. Zhang, and H. Zhang, "Using incompletely cooperative game theory in wireless mesh networks," *IEEE Network*, vol. 22, no. 1, pp. 39–44, Jan.-Feb. 2008.

15. L. Gao and X. Wang, "A game approach for multi-channel allocation in multi-hop wireless networks," in *MobiHoc '08: Proc. 9th ACM Int. Symp. on Mobile ad hoc networking and computing*, Hong Kong SAR, China, 2008, pp. 303–312.

16. Y. Song, C. Zhang, and Y. Fang, "Joint channel and power allocation in wireless mesh networks: A game theoretical perspective," *IEEE J. Sel. Areas Commun.*, vol. 26, no. 7, pp. 1149–1159, Sep. 2008.

17. E. Koutsoupias and C. H. Papadimitriou. Worst-case equilibria. In Proceedings of the 16th Annu Symposium on Theoretical Aspects of Computer Science, pages 404-413, 1999.

18. T. Roughgarden and E. Tardos. How bad is sel_sh routing? Journal of the ACM, 49(2):236- 259, 2002.

19. T. Rough garden and E. Tardos. Bounding the ine_ciency of equilibrium in nonatomic congestion games. Games and Economic Behavior, 47(2):389-403, 2004.

20. Z. Feng and Y. Yang, "Characterizing the impact of partially overlapped channel on the performance of wireless networks," in *Proc. IEEE GLOBECOM 2008.*, New Orleans, LA, Dec. 2008.

21. Vivek Srivastava, James Neel, Allen B. Mackenzie, Rekha Menon, Luiz A. Dasilva, James E. Hicks, Jeffrey H. Reed, and Robert P. Gilles," Using game theory to analyze wireless ad hoc networks"in IEEE Communication, FOURTH QUARTER 2005, VOLUME 7, NO. 4.