Power-Efficient Route Discovery (PERDP) for ODMA Systems

Ray-Guang Cheng, Jia-Yang Hung, and Yao-Yuan Liu

Department of Electronic Engineering,
National Taiwan University of Science and Technology,
Taipei 106, Taiwan, R.O.C.
{crg,M9202217,D9402404}@mail.ntust.edu.tw

Abstract. This work presents a power-efficient route discovery protocol (PERDP) to reduce signaling overhead of the power-efficient routing (PER) mechanism for Opportunity Driven Multiple Access (ODMA) networks. An analytical method was proposed to derive the control parameters to achieve a given connectivity probability. Simulation results demonstrate the accuracy of the analysis and the superiority of the proposed PERDP. It is found that the signaling overhead of the proposed PERDP is 12.03% and 24.85% lower than that of dynamic source routing (DSR) and PER mechanism, respectively, under 90% connectivity probability in a high UE-density environment.

1 Introduction

Opportunity Driven Multiple Access (ODMA) [1] is a cellular multihop relaying protocol that has been considered by the third-generation partnership project (3GPP) working group but finally dropped due to the concerns over implementation complexity, battery life of users on standby, and signalling overhead issues [2]. Most of these implementation issues are highly related to the chosen routing mechanism in ODMA. In ODMA, user data is exchanged between a sending mobile station (also known as user equipment (UE) in UMTS) and the base station (called Node B in UMTS) by being relayed through other intermediate UEs. The sending UE should establish a path through the intermediate UEs to Node B prior to data exchange, which introduces additional signaling overhead, and thus results in extra power consumption for certain UEs. Hence, a good routing mechanism with low signaling overhead would be essential while realizing ODMA.

The functions of ODMA closely resemble those of mobile ad-hoc networks (MANET) [3]. However, they differ mainly in that Node B is located in a well-known fixed position in ODMA; however, both communication parties are mobile in MANET. Several power-aware routing methods [4]-[9] have been proposed for MANET and ODMA cellular networks. Most of the proposed methods are evolved from dynamic source routing (DSR) protocol [10] and ad-hoc on-demand distance-vector (AODV) routing protocol [11]. Two significant assumptions are made in the aforementioned approaches. The first assumption is that each node retains the up-to-date location information and/or power metrics of the other nodes. This assumption may be effective in MANET but is not suitable for mobile cellular networks. Because each UE in a mobile cellular network does not have up-to-date information of other UEs due to the discontinuous reception (DRX) function. This assumption can be relieved by employing reactive-routing approaches [12]. However, existing reactive-routing approaches can only obtain the information of other UEs after executing route discovery; hence, some routing control messages are wasted on processing non-attainable ODMA requests (i.e., those requests whose power or latency requirements cannot be attained by utilizing the ODMA technology). The second assumption is that the extra power used by RREQ signaling is ignored. Because the RREQ in MANET is always flooded among all UEs with the UE's maximum transmission power and without hop-count limitation. Consequently, the UE's transmission power can be up to several Watts in a mobile cellular network and cannot be neglected.

In [13], we proposed a reactive-based routing mechanism, named power-efficient routing (PER), to solve the implementation problems of ODMA. Similar to existing reactive routing protocols, PER utilize flooding to delivers the route request (RREQ) to the destination (i.e., BS). Although flooding is necessary for discovering routes, it introduces extra radio interference to existing communications. Hence, it is beneficial to eliminate unnecessary flooding such that the interference can be minimized. However, the reduced flooding may result in a potential risk. That is, no route could be found if BS fails to receive any RREQ. Therefore, one of the implementation challenges in ODMA is to remove unnecessary flooding while diffusing RREQs to BS with a high probability.

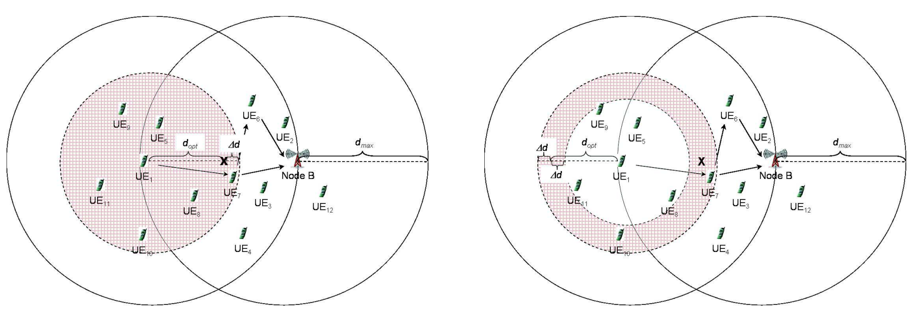
This paper presents a power-efficient route discovery protocol (PERDP) to reduce unnecessary flooding of PER in ODMA networks. The unnecessary flooding is prevented by reducing the the number of RREQ forwarding participants. PERDP utilizes the received power-strength, instead of connectivity or overheard information, to select valid forwarding participants. Hence, extra interference can be prevented. The rest of this paper is organized as follows. Before going into details, the background of PER mechanism is first introduced in Section 2. The proposed PERDP is described in Section 3, and its key parameters and their effect on the system performance are discussed. Section 4 presents an investigation of the proposed PERDP's performance via numerical analysis and simulation. Conclusions are finally drawn in Section 5.

2 PER Mechanism

A TDD-ODMA network comprising a Node B and several non-mobile ODMA-enabled UEs, which are identified by their user-specific identities (ODMA_IDs), is considered herein. To simplify the description, "UE" is used to denote an ODMA-enable UE in the rest of this paper. In an ODMA transmission, the UEs are categorized in three types: *SendingUE*, *BackerUE*, and *RelayUE*. A *SendingUE* originates the ODMA transmission. The other UEs that act as forwarding participants in the ODMA route discovery within the cell are *BackerUE*s.

Among these *BackerUE*s, some will be identified as *RelayUE*s, which are responsible for relaying data packets between the *SendingUE* and Node B. Note that UEs that do not have sufficient residual-power may optionally disable some ODMA functionalities (e.g., RREQ flooding) to reduce unnecessary power consumption.

The PER mechanism is used by a *SendingUE* to identify a minimum-power path to Node B. Prior to the route discovery, PER mechanism utilizes a co-linear model to estimate the optimal number of *RelayUE*, denoted by N_{opt}, required by the minimum-power path. It was shown in *Lemma 1* of [13] that the lower bound of the total power consumption for an ODMA link is achieved if the distances between any two adjacent relay nodes are all equal to d_{opt}, where $d_{opt}= d/(N_{opt}+1)$ and d is the distance between *SendingUE* and Node B. It suggests that a *SendingUE* can flood RREQ with transmission radius d_{opt} to discover the *RelayUEs* to achieve the lower bound in a co-linear network topology with sufficiently high UE-density. For normal or low UE-density, the lower bound may not be achieved, however, one can still discover *RelayUEs* in the vicinity of the expected equal-distance locations to identify a minimum-power path from all possible routes to Node B. As a result, the transmission radius of each *BackerUE* should be increased by an amount of Δd to discover those *RelayUEs*, as demonstrated in Fig. 1(a). In Fig. 1(a), UE_1 is *SendingUE* and $N_{opt} = 1$ is assumed; d_{max} is the maximum transmission radius of Node B and each UE, and the expected location predicted by *Lemma 1* is marked by 'X'. As demonstrated in 1(a), *BackerUE*s located in the region where the two circles overlap (i.e., UE_5, UE_7, and UE_8) could be possible *RelayUE* candidates. Hence, in PER, only these *BackerUE*s, rather than all *BackerUE*s in the entire cell, should forward RREQ during route discovery, which reduces the number of forwarding participants.



(a) (b)

Fig. 1. (a) A network topology illustrates the PER mechanism. (b)The basic concept of the PERDP mechanism.

The procedure of PER consists of three phases: access phase, path discovery phase, and path setup phase. In access phase, the *SendingUE* adjusts its transmission power to P_{ini} and sends an ODMA service request carrying P_{ini} to Node B. Node B can predict P_{opt} and N_{opt} from P_{ini}. By using these predicted P_{opt} and N_{opt}, Node B can check whether the ODMA request is attainable or not. For non-attainable ODMA requests, Node B simply terminates the procedure by replying the *SendingUE* with a rejection message. For attainable ODMA requests, Node B further derives P_{TX_RDP} and N_{opt}, and sends a confirmation message carrying P_{TX_RDP} and N_{opt} to the *SendingUE*. In path discovery phase, similar to DSR [10], the *SendingUE* broadcasts an RREQ through the ith paths to the Node B to collect $P_{total,i}$. In this phase, each *BackerUE* floods the RREQ with transmission power P_{TX_RDP} and discards the RREQ that exceeds the hop-count limitation N_{opt} . Based on the collected $P_{total,i}$, Node B can identify the minimum-power path. Finally, Node B sends an RREP packet back to the *RelayUEs* along the identified path in path setup phase. The derivation of P_{ini}, P_{TX_RDP}, and N_{opt} can be found in [13].

3 Power-Efficient Route Discovery Protocol

In this section, a power-efficient route discovery protocol (PERDP) is proposed to reduce the number of flooded RREQs in PER while maintaining an acceptable connectivity probability. In this section, the basic concept of PERDP is first described and the analytical method used to derive the control parameters is then elaborated. Finally, the procedure required to adopt PERDP to the PER mechanism is illustrated.

The basic concept of PERDP is illustrated in Fig. 1(b). It can be found that the flooded RREQs during the access phase of PER can be further reduced by selecting only *BackerUE*s located in the shaded ring region (which is bounded by an outer circle and an inner circle with radius $d_{opt} + \Delta d_{+}$ and $d_{opt} - \Delta d_{-}$, respectively) as forwarding participants. In this example, only UE_7 is selected as the *BackerUE* that is allowed to forward RREQ to its neighbors.

In PERDP, the transmission radius of RREQ flooded by *SendingUE* and *BackerUE*s is fixed and is set to be $d_{opt} + \Delta d_{+}$. In each flooding, only *BackerUE*s located in the ring region bounded the two circles with radius $d_{opt} + \Delta d_{+}$ and $d_{opt} - \Delta d_{-}$ are allowed to forward the RREQ. The flooding repeats until the RREQ reaches Node B or the RREQ has been forwarded by N_{opt} *BackerUE*s. The setting of Δd_{+} and Δd_{-} depends on the UE-density and a target connectivity probability P_s. The target connectivity probability is the minimum probability that a *SendingUE* can find a path, to Node B through exactly N_{opt} *RelayUE*s. One may increase P_s by enlarging Δd, but it also increases the number of flooded RREQs as well as the radio interference. Hence, there is a tradeoff between P_s and the flooding efficiency. In the following, an analytical model is proposed to determine P_s as a function of Δd and UE-density for the case of N_{opt}. Before going into details, the parameters used in the following analysis is summarized below:

A: the area of the cell under investigation.

m: the total number of UEs in the cell. Note that the UE-density is equal to m/A.
N_{opt}: the optimal number of *RelayUE* estimated by PER.
d: the distance between the *SendingUE* and Node B.
P_s: the connectivity probability, which is the probability that a *SendingUE* UE_0 can establish a path through N_{opt} *RelayUE*s to Node B. P_s is set by the network operator.
Δd_+: the outer distance offset used by PERDP.
Δd_-: the inner distance offset used by PERDP.
R: $R \triangleq d_{opt} + \Delta d_+$ is the radius of the outer circle. Note that R is also the maximum transmission range of each flooded RREQ.
r: $r \triangleq d_{opt} - \Delta d_-$ is the radius of the inner circle.
d_S: the distance between a given *RelayUE* and the *SendingUE*.
d_N: the distance between a given *RelayUE* and Node B.

Note that d_{opt}, Δd_+, Δd_-, d_s, and d_N can be estimated from the corresponding received power by applying the Friis free space equation as demonstrated in [13].

Figures 2(a) and (b) show a geometry model used to determine P_s for $N_{opt} = 1$. Two conditions are considered in deriving P_s: $\Delta d_+ \leq \Delta d_-$ and $\Delta d_+ > \Delta d_-$. In both cases, a *SendingUE* can find a route to Node B if there are at least one *BackerUE* located in the area A_0. Hence, the connectivity probability can be derived as

$$P_s = 1 - Pr\{\text{No } \mathit{BackerUE} \text{ is located in } A_0\} = 1 - (1 - \frac{A_0}{A})^m. \tag{1}$$

In Fig. 2(a), the case of $\Delta d_+ \leq \Delta d_-$ is depicted. Let x be the distance from a point in the shaded region to Node B. From the figure, it can be found that x falls in the range of $[d - R, R]$ and the length of the arc corresponding to radius x is $2x\theta$. Hence, the area of A_0 can be calculated by integrating the arcs for different x. That is,

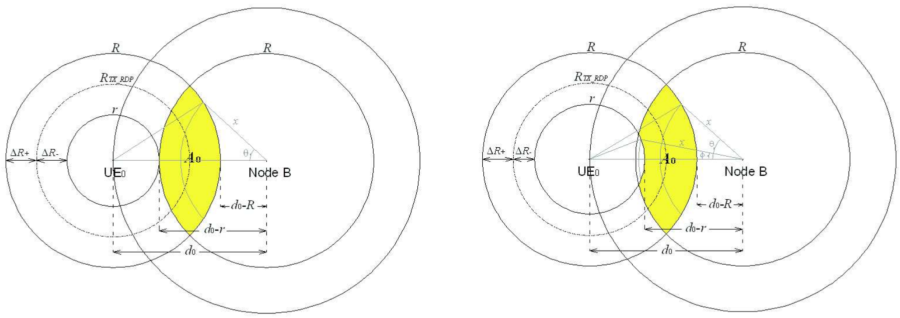
$$A_0 = \int_{d-R}^{R} 2x\theta dx = 2\int_{d-R}^{R} x \cdot cos^{-1}(\frac{x^2 + d^2 - R^2}{2xd})dx \tag{2}$$

The case of $\Delta d_+ > \Delta d_-$ is depicted in Fig. 2(b). Similarly, A_0 can be obtained by

$$\begin{aligned} A_0 &= \int_{d-R}^{R} 2x\theta dx - \int_{d-r}^{R} 2x\phi dx \\ &= 2[\int_{d-R}^{R} x \cdot cos^{-1}(\frac{x^2 + d^2 - R^2}{2xd})dx - \int_{d-r}^{R} x \cdot cos^{-1}(\frac{x^2 + d^2 - r^2}{2xd})dx] \end{aligned} \tag{3}$$

For given values of P_s, A, m, and d, R and r can be obtained by solving Eqs. (1) and (2) (or (3)).

For the easy of demonstration, the results of $\Delta d_+ = \Delta d_- \triangleq \Delta d$ is presented herein. Figure 3 shows the message flows employed to demonstrate a scenario



(a) (b)

Fig. 2. A single-hop example: (a) $\Delta d_{+} \leq \Delta d_{-}$ (b) $\Delta d_{+} > \Delta d_{-}$.

of PERDP using the example shown in Fig. 1(b). In this scenario, UE_1 is the *SendingUE*; UE_j, for j=2 to 12, are *BackerUEs*; and, $N_{opt} = 1$ is assumed. With PERDP, the access phase of the PER mechanism is modified as follows.

Access Phase :

Step 1. Prior to communicating with Node B, the *SendingUE* UE_1 measures P_{avg} , adjusts its transmission power to P_{ini} , and then sends an RRC_Connection_Req [14] carrying P_{ini} to Node B.

Step 2. The UEs that receive the RRC_Connection_Req message can detect the received power of the message then get the distance, d_S .

Step 3. Upon receiving the RRC_Connection_Req message, Node B adjusts its transmission power to P_{ini} and acknowledges an ODMA_Relay_Prepare carrying P_{TX_RDP} and N_{opt} to UE_1 .

Step 4. The UEs that receive the ODMA_Relay_Prepare message can detect the received power of the message then get the distance, d_N .

Step 5. After the UEs receive two messages, they will implement the *BackerUE* decision as illustrated in Fig. 4 . Note that each BackerUE can estimate d_S and d_N via open-loop power control.

Step 6. The UEs can resolve their state if they are the *BackerUE* and in operation mode. If the UEs which just receive one of two above messages before timeout period, they will transfer operation mode to sleep (SLP) mode.

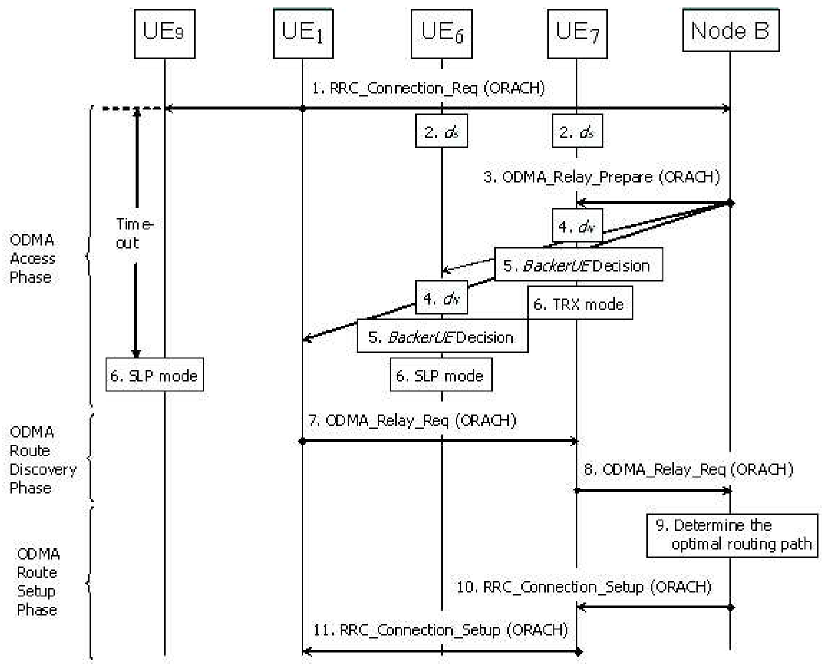


Fig. 3. Message flow of the PER with PERDP.

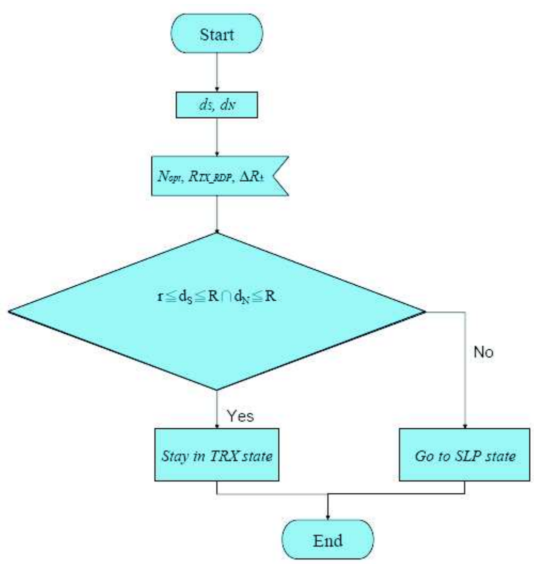


Fig. 4. BackerUE decision flow.

4 Numerical Results

Simulations were conducted on ns2 simulator to verify the effectiveness of the proposed PERDP. The load balancing capability of ODMA was not investigated herein. Hence, a single cell with 20 to 100 UEs was considered. All UEs were assumed to be uniformly distributed within a square area with dimensions 1km×1km. The following parameters were used in the simulation, $d = 600$ m, $R_{TX\_RDP} = 150$ to 200 (m) and $N_{opt} = 1$. In all case, ΔP is adjusted to guarantee a 90% successful connectivity probability (i.e., $P_{S\_min} = 0.9$)

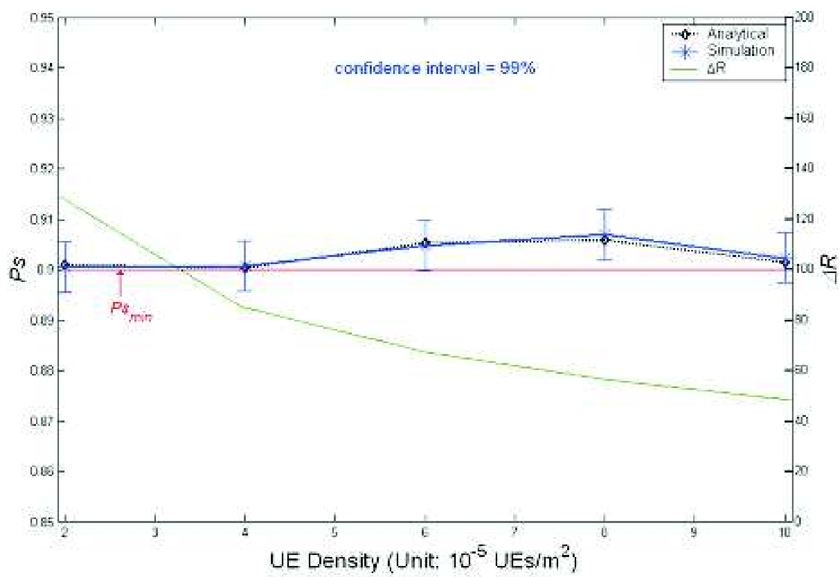


Fig. 5. Accuracy of the numerical analysis:1-hop.

Fig. 5 illustrates the accuracy of the numerical analysis for $N_{opt} = 1$. In this figure, the numerical analysis is indicated by a solid line and the simulation result is marked by a dotted line. It can be found the accuracy of the numerical analysis, where the simulation results always fall within the 95% confidence interval of the numerical analysis. The red solid line is used to indicate $P_{S\_min} = 0.9$. Fig. 6 demonstrates the performance improvement of the proposed PERDP algorithm compared to DSR and PER methods. In Fig. 6, three lines are used to illustrate the required total number of RREQs, N_{RREQ} , for establishing a ODMA path during the path discovery phase. The performance of DSR, PER and PERDP is marked by dotted squares, solid stars and dotted circles, respectively. It can be found that the total number of RREQs flooded by the *BackerUEs* is increased proportionally to the UE density. It is because that, in DSR, each UE always forwards the RREQ, and in PER, the number of the UEs that located in shaded area could be the *BackerUE* is still too much. The higher the UE density is, the more RREQs are flooded. In contrast, for a given successful connectivity probability of $P_{S\_min} = 0.9$, PERDP reduces ΔP as the increase of the UE density. Therefore, it approximates the optimal condition predicted by the PER mechanism. It is found that signaling overhead of the proposed PERDP is 12.03% and 24.85% lower than that in DSR and PER respectively for $P_{S\_min} = 0.9$ in high UE density environment.

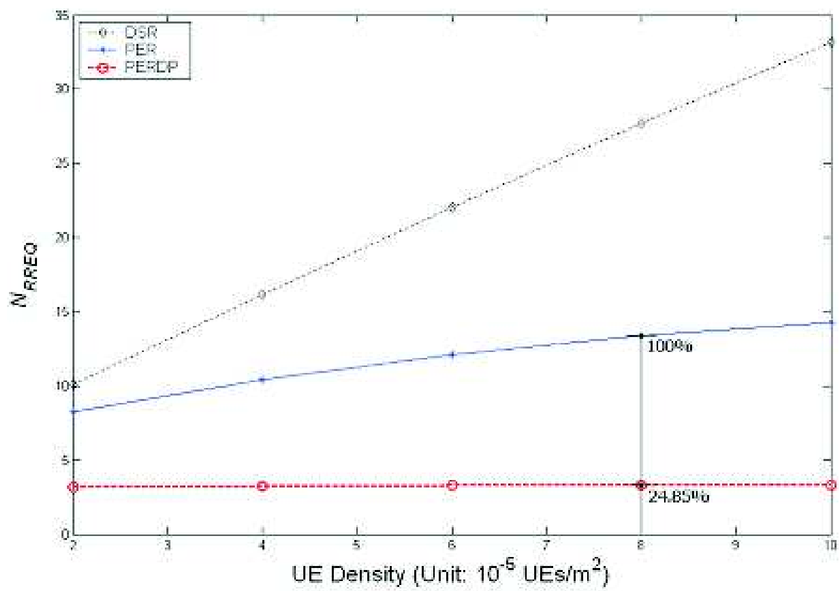


Fig. 6. The analysis of total number of RREQs:1-hop.

5 Conclusion

This paper presents a mechanism, named PERDP, to reduce unnecessary flooding of reactive routing protocols in ODMA networks. An analytical method was proposed to derive the control parameters required to discover a route for a given connectivity probability. The accuracy of the analysis is verified by simulation. Compared to DSR and PER mechanisms, it is found that the proposed PERDP may greatly reduce the number of flooded RREQs in PER. In this paper, only the case of a single *RelayUE* is investigated. The generalization of PERDP to a multiple *RelayUEs* environment is deserved to be studied in the future.

References

1. 3GPP, "Opportunity driven multiple access,"3G TR 25.924, v. 1.0.0, Dec. 1999.

2. T. Rouse, I. Band, and S. McLaughlin, "Congestion-based routing strategies in multihop TDD-CDMA networks," *IEEE J. Select. Areas Commun.*, vol. 23, no. 3, pp. 668–681, Mar. 2005.
3. A. J. Goldsmith and S. B. Wicker, "Design challenges for energy-constrained ad hoc wireless networks," IEEE Wireless Comm., vol. 9, no. 4, pp. 8-27, 2002.
4. S. Singh, M. Woo, and C.S. Mghavendra, "Power-aware routing in mobile ad hoc networks," Proc. of ACM/IEEE MobiCOM, pp. 181-190, 1998.
5. A. Michail and A. Epremides, "Energy efficient routing for connection-oriented traffic in wireless ad hoc networks," Wireless Networks, vol. 8, pp. 517V533, 2003.
6. J. H. Chang and L. Tassiulas, "Energy conserving routing in wireless ad-hoc networks," Proc. of IEEE INFOCOM, pp. 22-31, 2000.
7. V. Rodoplu and T. H. Meng, "Minimum energy mobile wireless networks," IEEE J. Selected Areas in Communications, vol. 17, no. 8, pp. 1333V1344, August 1999.
8. R. Wattenhofer, L. Li, P. Bahl, and Y. M. Wang, "Distributed topology control for power efficient operation in multihop wireless ad hoc networks," Proc. of IEEE INFOCOM, April 2001.
9. Vodafone Group, "ODMA routing with procedures for mobile originated calls, mobile terminated calls, and location update," Tdoc TSGR2#2(99) 179, 3GPP RAN WG2, March 1999.
10. D. Johnson, and D. Maltz, "Dynamic source routing in ad hoc wireless etworks," Mobile Computing, pp. 153-181, 1996.
11. C. E. Perkins, E. M. Belding-Royer, and I. Chakeres, "Ad hoc on demand distance vector (AODV) routing," IETF Internet draft, Oct 2003,
12. A. Safwat, H. S. Hassanein, and H. T. Mouftah, "Structured proactive and reactive routing for wireless mobile ad hoc networks," The Handbook of Ad Hoc Wireless Networks, CRC Press, 2002.
13. Ray-Guang Cheng, Shin-Ming Cheng, and Phone Lin, "Power-efficient routing (PER) mechanism for ODMA systems," IEEE Transaction on Vehicular Technology, vol. 55, no. 3, May 2006.
14. H. Karl (Editor), "An overview of energy-efficiency techniques for mobile communication systems," Report of AG Mobikom WG7, Oct. 2003.