Traffic Convexity Aware Cellular Networks: 
A Nomadic Heavy User Perspective

Taehyoung Shim, Jihong Park, Seung-Woo Ko, Seong-Lyun Kim,
School of Electrical and Electronic Engineering
Yonsei University, Seoul, Korea
e-mail: {teishim, jhpark.james, swko, slkim}@ramo.yonsei.ac.kr

Beom Hee Lee, and Jin Gu Choi
LG Electronics, Korea
e-mail: {beomhee.lee, jingu.choi}@lge.com

Abstract—Rampant mobile traffic increase in modern cellular networks is mostly caused by large-sized multimedia contents. Recent advancements in smart devices as well as radio access technologies promote the consumption of bulky content, even for people in moving vehicles, referred to as nomadic heavy users. In this article the emergence of nomadic heavy user traffic is observed by field experiments conducted in 2012 and 2015 in Seoul, Korea. The experiments reveal that such traffic is becoming dominant, captured by the 8.62 times increase in nomadic heavy user traffic while the total traffic increased 3.04 times. For the purpose of resolving this so-called nomadic heavy user problem (NHP), a cell association algorithm is proposed. The association exploits the user traffic pattern that is convex-shaped over velocity, i.e. walking user traffic is less than stationary or nomadic user traffic, which was also experimentally discovered first by the field trials. Numerical evaluation verifies the proposed association outperforms the cell range expansion (CRE) based scheme in practice as the NHP becomes severe. In addition to the cell association, several complementary techniques are suggested in line with the technical trend toward 5G.

Keywords—Nomadic heavy user, user convexity, user traffic, user velocity, cell association, handover, load balancing, next generation wireless communication system, heterogeneous networks
Figure 1. An experimental example of a movement trace, velocity, and the corresponding data usage of a typical user in Seoul, Korea in 2012. The user remained stationary (blue) at $A$ for a while, and walked (green) to $B$. After a short stay at $B$, he moved to $C$ by a vehicle (orange). The corresponding data usage indicates that the user in stationary and nomadic mobility states consume more data than during the walking state.
I. INTRODUCTION

The nomadicity of users has long been regarded as the traffic pattern of moving users whose data consumption is mostly concentrated on their stationary states [1]. The recent advancement in cellular networks along with the smart device proliferation, however, promotes the data consumption during the in-transit states. This emerging trend may considerably alter the overall traffic pattern if the dominant traffic volume originates from in-vehicle passengers who are able to consume even a large-sized multimedia content. We thus redefine such users as nomadic heavy users, and revisit their impact on the overall traffic pattern.

From a network design perspective, nomadic heavy users consuming bulky multimedia contents in vehicles may become a critical challenge for the next generation cellular networks. Indeed, their demands for large amounts of resource per se are a strain on network operators. In addition, frequent handovers incurred by quickly moving vehicles force the spectral efficiencies to take a nosedive. Unabated nomadic heavy user traffic would therefore bring about the rapid depletion of available frequency resources, degrading network capacity.

In this article we argue that such a nomadic heavy user problem (NHP) is imminent based on field experiments. As a remedy for the NHP, we focus on a convex-shaped user traffic pattern first proved by the experiments, and propose the user convexity aware cell association accordingly.

CONVEX TRAFFIC OVER VELOCITY

Users riding a bus are able to watch large-sized video contents [2, 3] as in stationary users whereas walking users cannot concentrate on these types of contents [4], which may lead to convex-shaped user traffic over velocity. Our field experiments conducted in 2012 and 2015 confirm such a traffic pattern conjecture. Furthermore, the results reveal that the nomadic heavy user traffic increase is almost three times larger than the walking users’ during the period. This accelerating heavy-to-light traffic divergence motivates us to exploit the convex traffic pattern for a cellular network design so as to resolve the NHP.

CONVEX TRAFFIC AWARE NETWORK DESIGN

We consider a two-tier downlink cellular network comprising small and macro cells, and design the network in a way that improves average rate while guaranteeing each
user’s minimum rate requirement. Recalling the NHP, our prime concern is nomadic heavy users’ minimum rate satisfaction lest it become a bottleneck. We thus propose a cell association algorithm that increases the nomadic user rate by means of sacrificing the walking user rate. The lowest traffic volume of walking users from the convex traffic pattern allows them to put up with such rate degradation while improving average rate. In addition to the cell association algorithm, we suggest several complementary NHP solutions from the lower-to-higher layer perspectives. Their layer-transcending combinations would boost to alleviating the NHP.

II. USER TRAFFIC PATTERN OVER VELOCITY

In a traditional cellular network, moving user traffic has not been regarded as a major burden since they have rarely requested data [5] due to the limitation of radio technologies. The recent rise of smart devices and advancements in cellular technologies, however, make the data consumption paradigm shift toward moving users. This motivates us to revisit the mobile data traffic pattern with respect to user velocity. In this section we investigate traffic pattern over velocity through field experiments, which allows us to foresee that the NHP is imminent.

EXPERIMENTAL SETUP

Our objective is to establish a downlink data traffic tendency along with user velocity. For this purpose, we conducted field experiments twice in Seoul, Korea during: (i) May–June in 2012 and (ii) March in 2015 when LTE penetration rates respectively are 11.2% and 63.4% [6]. In the experiments, total 152 participants are recruited, and measured their downlink data usage with the corresponding velocities under the environments in Table 1.

In the 2012 experiment, we measured such data via LifeMap [7], an Android application developed by the department of computer science at Yonsei University. For every five minutes, the application kept track of the user location and the aggregate data usage during the period. To derive user velocity from the location data, we assume each user linearly moves in-between two consecutive locations during such a short interval. We then calculate the velocity in a way that the corresponding distance is divided by
the time interval.

In the 2015 experiment, the data measuring application is replaced by My Data Manager\(^1\) combined with Moves\(^2\), respectively collecting data usage and user locations. Such replacements were inevitable since the application used in 2012 had not been updated and thus was no longer compatible with the participants’ devices in 2015. Nevertheless, its impact on the collected data is negligible, and therefore its traffic pattern comparison with the result in 2012 is valid. Further justification of this issue is deferred to a supplementary document\(^3\) that also incorporates the experimental procedures in detail.

For tractability, user velocities are divided into three groups: stationary, walking and nomadic. Stationary users do not move during the given time interval, interpreted as people working in an office or sitting in a café. Walking users move with velocities of up to 10 km/h corresponding to a comfortable running pace \[8\]. Such users thus indicate strolling or jogging people. Nomadic users move by vehicles, and are hereafter identically treated as nomadic heavy users for notational brevity. Their velocities range from 10 km/h to 196.6 km/h where the latter corresponds to a high speed train. Figure 1 provides a visual example of our experimental data collection.

| Year | 2012 | 2015 |
|------|------|------|
| **Number of participants** | 82 (male: 61, female: 21) | 70 (male: 54, female: 16) |
| **Age of participants** | avg. 25.9 | avg. 27.8 |
| **Experimental period** | avg. 1.28 weeks | avg. 1.13 weeks |
| **Radio access technology** | WCDMA / LTE | WCDMA / LTE / LTE-A |
| **Measurement applications** | LifeMap | My Data Manager, Moves |
| **Velocity** | *Walking*: up to 10 km/h (avg. 2.58 km/h) | *Nomadic*: above 10 km/h (avg. 31.9 km/h) |

Table 1. Experimental environments.

\(^1\) My Data Manager; http://www.mydatamanagerapp.com.
\(^2\) Moves; https://www.moves-app.com.
\(^3\) Due to the limited space, further experimental processes in detail are deferred to the following supplementary document: http://ramo.yonsei.ac.kr/archive/convexityexperiment.pdf.
KEY OBSERVATIONS

Our field experiment results are summarized in Figure 2. Comparing the results of 2012 and 2015, we provide three key observations as follows.

1) **Total traffic volume increase** – The average daily downlink data usage in 2015 increased by 3.04 times from 2012 (47.66 → 145.05 MB/day). This explosive traffic growth results from advancements in LTE/LTE-A as well as prevailing smart devices as expected in [9].

2) **Aggregate walking and nomadic user traffic proportion increase** – Aggregate walking and nomadic user traffic proportion of the total traffic volume increased by 2.64 times (14.74 → 38.93%). Not only was there a rapid growth in walking and nomadic user traffic, but also the slow growth of stationary user traffic. Walking and nomadic users are comfortable with consuming multimedia contents thanks to high performance smart devices [2, 3] and mobility supporting technologies such as seamless handover schemes [10], leading to increased walking and nomadic user traffic. Stationary users, on the other hand, frequently offload their traffic to Wi-Fi [5], resulting in the slow growth of stationary user traffic.

3) **Nomadic heavy user traffic proportion increase** – Nomadic user traffic proportion increased by 2.83 times (10.35 → 29.29%). This corresponds to the 8.62 (4.93 → 42.48 MB/day) times traffic volume growth, which is much larger than the 3.04 times total traffic volume growth during the same period. By comparing the result with the 2.64 times traffic proportion increase of aggregate walking and nomadic users, it is observed that walking user traffic did not increase as much as nomadic user traffic, leading to a convex-shaped traffic pattern also captured by a typical user’s example in Figure 1. Such a pattern emerges from the fact that nomadic users riding vehicles are able to concentrate on bulky multimedia contents whereas walking users are not [4]. We predict this tendency will further intensify when driverless cars will enable the drivers to be able to enjoy the bulky contents in the near future.

The above experimental results underpin our prediction that nomadic heavy user traffic will become dominant. We further anticipate that the NHP will become even
more challenging when considering the recent cellular base station densification trend toward ultra-dense networks [11]. It may incur more frequent handovers, degrading the spectral efficiency of nomadic users. In the following section, we thus propose a novel network design approach, to cope with the NHP.

![Figure 2](image.png)

Figure 2. Total traffic volumes and traffic volume proportions of stationary, walking, and nomadic users in 2012 and 2015. Nomadic heavy user traffic volume increased by 8.62 times from 2012 to 2015 (4.93 → 42.48 MB/day) while total traffic volume only increased by 3.04 times (47.66 → 145.05 MB/day), leading to the 2.83 times (10.35 → 29.29%) nomadic heavy user traffic proportion increase.

### III. USER CONVEXITY AWARE NETWORK DESIGN

This section introduces a novel cell association algorithm to combat the NHP by utilizing the preceding traffic pattern from our field experiments. The scheme gives association priorities to nomadic and stationary users, and not to walking users, so as to increase the nomadic user rate as well as the average rate of aggregate users. Since the association priority determination is vital to the proposed algorithm, we define a metric *user convexity* that quantifies the difficulty of the NHP and thereby determines the extent to which the associations should be prioritized. Such a user convexity aware association pertinent to the NHP is numerically evaluated, and its implementation under practical cellular architecture is described in the following subsections.
Figure 3. Traffic volume over velocity and its corresponding user convexity. Stationary and nomadic user traffic volumes are larger than the walking user volume. The difference increased from 2012 to 2015, measured by 1.29 times (user convexity: 2.35 \rightarrow 3.04) increase in user convexity defined as the traffic volume ratio of nomadic users to walking users.

**User Convexity**

User convexity is defined as the traffic volume ratio of nomadic users to walking users, geometrically incorporating the convexity of traffic volume curve over velocity. This value indicates the difficulty of the NHP. As an example, high user convexity corresponds to severe NHP due to heavy traffic generating nomadic users as well as their large traffic proportion of the entire traffic volume. Figure 3 represents our field experimental results with user convexity. The value in 2015 increased by 1.29 times from 2012 (2.35 \rightarrow 3.04). This emphasizes the necessity of designing a user convexity aware network in order to combat the NHP.
USER CONVEXITY AWARE CELL ASSOCIATION

We consider a two-tier cellular network comprising macro and small cells, and propose a cell association algorithm that facilitates the NHP mitigation by virtue of putting additional burden on other users. To minimize the inevitable damage, the victims to the algorithm are walking users whose traffic volume is the lowest. The scheme associates them with more congested cells in order to vacate frequency resource for nomadic users. User convexity at this point plays a key role to determine the association bias achieving the required resource to be vacated.

To be more specific, consider rate coverage defined as the probability that each user group’s average rate exceeds a target amount [12] set as its expected traffic volume. The proposed user convexity aware cell association aims at maximizing the rate coverage averaged over users while guaranteeing at least a target rate coverage for each user group. In this problem, the minimum rate coverage constraint of nomadic users is likely to be a major bottleneck due to the NHP. The proposed scheme thus tries to satisfy the nomadic user’s minimum rate coverage constraint with the highest priority, and then increase the average rate coverage as much as possible.

Such a goal is achieved via the following three-stage operations.

(Stage 1) Neglecting walking and nomadic users, set the association bias for stationary users toward small cells, which maximizes their own rate coverage. This stage increases average rate coverage by prioritizing the biasing factor decision of stationary users whose traffic volume are the majority, therefore heavily affecting the average rate coverage.

(Stage 2) Given the stationary user bias, set the association bias for walking users more toward the direction of small cells along with user convexity increase, which more vacates macro cell resource for nomadic users. The stage puts macro cell resource aside by means of walking users’ associating more with small cells, of which the required macro cell vacancy is measured via user convexity.

(Stage 3) Given the stationary and walking user biases, set the association bias for nomadic users in such a way that their rate coverages are maximized, of which the direction is likely to be biased toward macro cells. At this stage, the procured macro cell resource is utilized in order to reduce congestion at the cells associated with nomadic users, thereby alleviating the NHP.

4 Mathematical algorithm descriptions are elucidated in: http://ramo.yonsei.ac.kr/archive/convexitydesign.pdf.
It is worth mentioning that our proposed association is designed on the basis of cell range expansion (CRE) applied in cellular networks in practice [13]. The CRE increases the number of user associations with small cells (or small cell coverage) so that it can balance the associations between small and macro cells. This small cell biased association complements the short range of small cell coverage due to its low transmission power. The biased association however resorts to sacrificing spectral efficiency maximization in return. The trade-off between balancing associations and increasing spectral efficiency should therefore be optimized for rate maximization via adjusting association bias. Our proposed user convexity aware cell association intentionally breaks the rate optimal bias of the CRE for improving nomadic user rate coverage. Such a procedure is user traffic and velocity (i.e. user convexity) specific, of which these details are not incorporated in the CRE.

**NUMERICAL EVALUATION**

For a given total traffic volume, we numerically evaluate the average rate coverage of user convexity aware association. For different total traffic volumes, we additionally derive the required bandwidth to achieve the minimum rate coverage requirements.

Figure 4 illustrates the average rate coverage of user convexity aware association as a function of user convexity. Total traffic is given as 145.05 MB/day that corresponds to our results in 2015. The user group ratios are assumed as our experimental investigation; the group ratios of stationary, walking, and nomadic users are respectively 89.72%, 4.70% and 5.58%. For given 10 MHz downlink bandwidth, our proposed association (thick solid blue) outperforms CRE (thin solid orange), and the gap becomes large along with the user convexity increase. Such a rate coverage of the proposed association algorithm accords with at least 98% of the full-search performance (dotted black) for all user convexity values. In addition, when the minimum rate coverage thresholds are identically fixed at 0.8 for all users, the proposed scheme guarantees the minimum requirements for higher user convexity values, as opposed to CRE, captured by their vertical thresholds respectively at user convexity values of 5.2 and 7.1. These results indicate our proposed association is useful for severe NHP, i.e. high user convexity.

Figure 5 visualizes the required bandwidth to satisfy the minimum rate coverage requirements of users. The result validates our assertion that convexity aware
association requires less bandwidth than CRE. It also shows that the required bandwidth gap between our proposed scheme and CRE becomes large when total traffic is doubled. Such results in Figures 4 and 5 consequently imply that user convexity aware association is superior when it comes to coping with more severe NHP as well as higher total traffic volume, in accordance with the forthcoming environment expected by our field experiments.

**Figure 4.** Average rate coverage with respect to user convexity. For a sufficiently high user convexity, user convexity aware association provides higher average rate coverage than CRE, close to the optimal performance achieved by full search (total traffic = 145.05 MB/day, bandwidth = 10 MHz, rate coverage threshold = 0.8, user density: [stationary, walking, nomadic] = [0.8972, 0.0470, 0.0558]/m²).
Figure 5. Required bandwidth to guarantee the minimum rate coverage requirements of users. Total traffic increase twice from 145.05 to 290.1 MB/day results in the larger required bandwidth gap between user convexity aware association and CRE (rate coverage threshold = 0.8, user density: [stationary, walking, nomadic] = [0.8972, 0.0470, 0.0558]/m²).

**IMPLEMENTATION UNDER PRACTICAL ARCHITECTURE**

The proposed user convexity aware cell association can be implemented under standard cellular architecture, in practice. Cloud Radio Access Network (C-RAN) [14] in LTE core architecture enables the association via acquiring user request data amount and user velocity information. Such information is by default collected by base stations. A base station receives its associated user’s data request amount, and sends it to C-RAN. In a similar manner, the base station collects user location information comprising the desired signal timing advance, measured reference signal strength, and/or a Global Navigation Satellite System (GNSS) signal. This location information is reported to Evolved Serving Mobile Location Center (E-SMLC) in C-RAN at intervals of from 1 to 64 seconds [15]. C-RAN then calculates user velocities based on the reported information, and combines them with the corresponding data request amounts. The resultant information is used to determine the user convexity of the network and its matching association bias for the user groups having different velocities.
IV. CONSIDERATIONS AND FUTURE CHALLENGES

The low volume of walking user traffic plays a key role in our proposed user convexity aware association. Emerging wearable devices however may increase walking user traffic, leading to a weakening of the proposed algorithm’s performance. Moreover, wirelessly powered [16] devices in the future will make walking users free from battery depletion, and hence consume more traffic, which may further degrade the proposed association. It is therefore necessary to keep an eye on the traffic pattern over velocity as in our field experiments. For the preparation of such scenarios where our proposed scheme is hardly viable, complementary NHP solutions from different perspectives are suggested, opening interesting avenues for future research as follows.

**Handover reduction via dual connections** – The high mobility of nomadic users by itself contributes to the NHP due to its frequent handovers downgrading spectral efficiency. Dual connectivity [17], establishing both macro and small cell connections respectively for control signaling and data downloading, can be a possible solution. It would reduce the number of handovers, which would be conductive to alleviating the NHP.

**In-vehicle communication capability enhancement** – The rooftop transceiver installation of vehicles as a relay, a moving cell [18], enables a group-wise handover of nomadic users, and allows users to be free from vehicle penetration loss, increasing the ability to cope with the NHP. In addition, the promising massive antenna array equipment in 5G by utilizing the space in vehicles may further boost the capability.

**Caching at predictive nomadic users** – Prefetching data to the stationary or walking users who are expected to become nomadic users shortly afterwards reduces nomadic user traffic. User context based movement prediction enables such data caching. The context of those predictive nomadic users is in accord with, for instance, walking users around a parking lot or stationary users at a bus stop. Intelligent sensors in smart and wearable devices will aid in the prediction, and make this caching scenario viable in the near future.

**Convexity aware buffer management and its layer-transcending optimization** – The low nomadic user spectral efficiency requires larger buffer sizes than the stationary users’ in order to mitigate multimedia playback interruptions. User convexity at this point determines the amount of buffer size difference between users. Regarding a real time service where buffer management is no longer available, however, buffer size
should be adjusted in an opposite direction for the latency minimization. In this respect, such a high layer aid is necessary to be in line with the said lower layer operations for the NHP. Extensive preceding works on service-oriented-architecture (SoA), a service-specific and layer-transcending network design framework [19], can provide its cross-layer optimization guidelines. From the SoA perspective, this article suggests a concept that a service of nomadic users can be distinct from that of stationary users even though they consume the same multimedia content. Research on this beyond SoA nature would also be an interesting topic.

V. CONCLUSIONS

This article presents a two-fold experimental discovery of cellular user traffic in conjunction with velocity. The first compelling evidence is the rapid growth of nomadic heavy user traffic, i.e. the NHP. The second noticeable observation is the low traffic volume of walking users, yielding a convex traffic pattern. To circumvent the difficulty of the NHP, a biased cell association algorithm is proposed, which sacrifices walking user associations for increasing nomadic user rate. Such an algorithm relieves the NHP regardless of the subordinated walking user associations thanks to the convex traffic pattern. From the opposite angle, the proposed algorithm’s dependency on the convex traffic pattern however can be a major drawback. Its follow-up experiments by periods thus will be necessary for years ahead. Furthermore, other complementary techniques pertinent to the NHP should be required. Concerning the recent technical trends toward 5G, dual connectivity, massive antenna array equipped moving cells, predictive caching, and layer-transcending buffer management would be such candidates, and also could be the further extension to this work.

ACKNOWLEDGEMENT

The authors appreciate Jeemin Kim and Han Cha for their contributions respectively to the cell association analysis and the 2015 experiment, as well as Sunyoung Lee in LG Electronics for her helpful feedback. The authors warmly thank Ying-Dar Lin and anonymous reviewers for the valuable comments enabling us to substantially improve the earlier version of this article. This research has been supported by LG Electronics Co., Ltd.
REFERENCES

[1] L. W. McKnight, J. Howison and S. Bradner, “Wireless Grids: Distributed Resource Sharing by Mobile, Nomadic, and Fixed Devices,” *IEEE Internet Computing*, vol. 8, no. 4, 2004, pp. 24–31.

[2] H. Riiser *et al*., “Video Streaming Using a Location-based Bandwidth Lookup Service for Bitrate Planning,” *ACM Trans. Multimedia Computing, Commun., and Appl.*, vol. 8, no. 3, 2012, pp. 24:1–24:19.

[3] Y. Yuan, M. Raubal and Y. Liu, “Correlating Mobile Phone Usage and Travel Behavior: A Case Study of Harbin, China,” *Computers, Environment and Urban Systems*, vol. 36, 2012, pp. 118–130.

[4] M. Yamada *et al*., “Using a Smartphone While Walking: A Measure of Dual-tasking Ability as a Falls Risk Assessment Tool,” *Age and Ageing*, vol. 40, no. 4, 2011, pp. 516–519.

[5] K. Lee *et al*., “Mobile Data Offloading: How Much Can WiFi Deliver?” *IEEE/ACM Transactions on Networking*, vol. 21, no. 2, 2013, pp. 536–550.

[6] Netmanias Reports, “Korea Communication Review: Q2 2015,” Apr. 2015; http://www.netmanias.com

[7] Y. Chon and H. Cha “LifeMap: A Smartphone-based Context Provider for Location-based Service,” *IEEE Pervasive Computing*, vol. 10, no. 2, 2011, pp. 58–67.

[8] R. W. Bohannon, “Comfortable and Maximum Walking Speed of Adults Aged 20-79 Years: Reference Values and Determinants,” *Age and Ageing*, vol. 26, no. 1, 1997, pp. 15–19.

[9] Ericsson, “Ericsson Mobility Report,” Jun. 2014; http://www.ericsson.com

[10] Y. Zhou and B. Ai, “Handover Schemes and Algorithms of High Speed Mobile Environment: A Survey,” *Computer Commun.*, vol. 47, 2014, pp. 1–15.

[11] J. Park, S.-L. Kim, and J. Zander, “Asymptotic Behavior of Ultra-Dense Cellular Networks and Its Economic Impact,” *Proc. IEEE Global Commun. Conference (GLOBECOM)*, Austin, United States, Dec. 2014.

[12] S. Singh, H. S. Dhillon, and J. G. Andrews, “Offloading in Heterogeneous Networks: Modelling, Analysis, and Design Insights,” *IEEE Trans. Wireless Commun.*, vol. 12, no. 5, 2013, pp. 2484–2497.

[13] 3GPP TR 36.872, “Small Cell Enhancements for E-UTRA and E-UTRAN – Physical Layer Aspects,” v. 12.1.0, Dec. 2013; ftp://ftp.3gpp.org

[14] China Mobile Research Institute, “C-RAN: The Road towards Green RAN,” white paper, v. 3.0, Jun. 2014.

[15] 3GPP TR 36.355, “Evolved Universal Terrestrial Radio Access (E-UTRA) – LTE Positioning Protocol (LPP),” v. 12.2.0, Jun. 2014; ftp://ftp.3gpp.org

[16] S.-W. Ko, S. M. Yu and S.-L. Kim, “The Capacity of Energy-constrained Mobile Networks with Wireless Power Transfer,” *IEEE Commun. Letters*, vol. 17, no. 3, 2013, pp. 529–532.

[17] 3GPP TR 36.842, “Study on Small Cell Enhancements for E-UTRA and E-UTRAN – Higher Layer Aspects,” v. 12.0.0, Dec. 2013; ftp://ftp.3gpp.org
[18] Y. Sui et al., “Moving Cells: A Promising Solution to Boost Performance for Vehicular Users,” *IEEE Commun. Mag.*, vol. 51, no. 6, 2013, pp. 62–68.

[19] S. Kashihara, K. Tsukamoto and Y. Oie, "Service-oriented Mobility Management Architecture for Seamless Handover in Ubiquitous Networks," *IEEE Wireless Commun. Mag.*, vol. 14, no. 2, 2007, pp. 28–34.