Performance Analysis for Content Distribution in Crowdsourced Content-Centric Mobile Networking

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Abstract. Content-Centric Networking emerges as a promising paradigm which has a better content distribution efficiency and mobility via named data and in-network caching compared with the IP-based network. However, providing a high quality of experience in content distribution of Content-Centric Mobile Networking (CCMN) is challenging due to the heterogeneous networks, varying wireless channel conditions and incentive strategies to mobile users. In this work, we propose a novel crowdsourced content distribution framework for CCMN. This framework enables the nearby mobile users to crowdsource their caching resources and radio links for cooperative content distribution. We formulate the problem as the maximization of the payoff of all users which considers content retrieve time and energy cost. Further, we analysis the upper bound and lower bound of the proposed system in term of user payoff, which can be a benchmark for the future scheduling algorithms and incentive mechanisms design.

Keywords: Information-Centric Networks
Content-Centric Networking · Mobile crowdsourcing
In-network caching

1 Introduction

The exponentially growing mobile cellular network traffic is evolving from the steady increase in demand for conventional host-centric communications, such as phone calls and text messages, to the explosion of content-centric communications, such as social networks, video streaming and content sharing [1–3]. The mobile cellular network model of today is still IP-based Internet which is originally designed as a communication model, e.g., a conversation between exactly two machines. However, according to the Cisco Visual Networking Index [4], mobile video will increase 9-fold between 2016 and 2021, accounting for 78

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percent of total mobile data traffic. We can see that one of the main applications of the mobile cellular networks today is the content distribution and retrieval, especially for multimedia content.

To better support global information publication, dissemination and retrieval, Content-Centric Networking (CCN) [5] (or Named-Data Networking) has been proposed. CCN is one of the promising clean-slate Information-Centric Network (ICN) architectures which try to establish a new network architecture to adapt to the characteristics of current Internet. CCN names content directly and concerns the security of naming content rather than transmission path. In-network caching is a fundamental property of CCN, and it is the key to reduce redundant transmission and improve bandwidth utilization.

It is a challenging issue in Content-Centric Mobile Networking (CCMN) that how to effectively utilize these existing capabilities for massive content distribution in mobile networks. In today's mobile networks, caching and computing capabilities are already ubiquitous, both at base stations and user devices. However, providing high quality of experience for content distribution in CCMN is challenging due to the heterogeneous networks and varying wireless channel conditions [6,7]. Moreover, for mobile users, not all users are willing to share their cache and radio resources because of 3G/4G communication expense and battery power consumption.

Some of the existing work on CCMN focus on video streaming. ICN enabled Peer to Peer applications are proposed for live adaptive video streaming in cellular networks [8–10]. These applications enable a small set of neighbouring devices with cellular/Wi-Fi connections to increase the quality of video playback by using the Wi-Fi to share the portion of the live stream downloaded by each peer via the cellular network. However, these work focus on a single video streaming for multiple users, rather than multiple content for multiple users. Moreover, none of them consider whether or not the cooperative users are willing to share their cache and radio resources.

To improve the efficiency of content distribution in CCMN, we propose a crowdsourced content distribution framework for CCMN inspired by adaptive video streaming technologies [11,12]. This framework enables the nearby mobile users forming a cooperative group (via WiFi or Bluetooth) to crowdsource their caching resources and radio links for cooperative content distribution. We formulate the problem as the maximization of all users' payoff and analysis the upper bound and lower bound of proposed system. The performance analysis results can serve as a benchmark for the future scheduling algorithm and incentive mechanism design.

2 Network Architecture

Due to named data and in-networking caching, CCN achieves better efficiency and mobility on data distribution than traditional IP based networks. In order to make full use of CCN features, we propose a crowdsourced mobile content distribution framework for CCMN, called Crowdsourced Content-Centric Mobile

Networking (CCCMN). As illustrated in Fig. 1, the network scenario of CCCMN consists of a small set of neighbouring mobile users (mobile cellular devices), Base Stations installed CCN protocol stack, backbone of CCN network and Content Providers (CPs).

We consider a set I of mobile users, and each mobile device of users has several interfaces (e.g., Cellular, WiFi, Bluetooth) available for simultaneous communications. All mobile devices will be equipped with name-based routing and content caching. Users move randomly in a certain area, and nearby users can form a cooperative group (via WiFi) and crowdsource their radio connections and cache resources for cooperative content distribution. Each user connects to Base Station (BS) by cellular network (3G/4G) with varying link capacity. Although incentive mechanism is a key issue which motivates all users to be willing to participate in CCCMN system to improve the performance of whole network, here we firstly focus on the CCCMN framework.

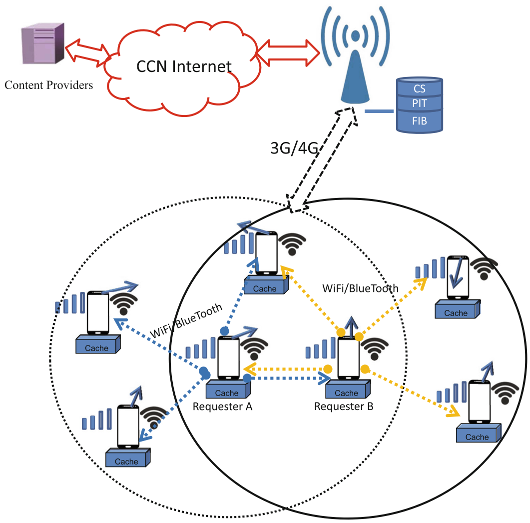

Fig. 1. An example of CCCMN network scenario

We consider the operation in a period of continuous time $\mathcal{T} \triangleq [0, T]$, where $t = 0$ is the initial time and $t = T$ is the ending time. The cellular link capacity of user i is denoted by $r_i^c(t)$, where $t \in [0, T]$. BSs are equipped with CCN protocol stack in network layer and have large cache capacity. Requests and data are transmitted between BSs and CPs via the backbone of CCN. BSs calculate the popularity of each content and cache the popular content to avoid the retransmission of popular data.

We use a set F to denote all content files requested by users I, and f is a single content file, $f \in F$. $|F|$ and $|f|$ represent the whole catalog size and the size of content f, respectively. We consider a typical CCN standard, where a single content file f is partitioned into multiple chunks by CPs, $f = \{f^1, f^2, ..., f^K\}$. Let $|f^k|$ signify the *k-th* chunk size of content file f. Users request a content by the sequence of chunks. Requested chunks are cached in the devices it passed by and if there's no enough cache space, stale chunks will be replaced by fresh chunks based on the cache replacement schemes.

3 Problem Formulation

The system model of CCCMN consists of three procedures: the first step is to aggregate requests and recruit participants; the aim of second step is to assign the task to each participant rationally base on some scheduling policies and each participant download the uncached chunks by cellular link; the last step is to transmit the downloaded chunks and/or cached chunks to each requester by the D2D connections (WiFi/BlueTooth). There are two kinds of users, to distinguish them we call **requesters** as the users who send the original request for the chunks, and we call **participants** as the users who help the requesters by the cached chunks or to download the chunks by cellular connections. No doubt that the requesters can also to be the participants and help themselves to download the chunks by cellular network.

3.1 Content Retrieve

In time $[0, T]$, all requested content files are represented by a set $S^{\dagger} = \{f_j | f \in F, j \in I\}$, where f_j denotes the content file requested by requester user j. The task of $S^{\dagger}$ is assigned to participants by chunks for the cooperative content distribution. After receiving the task, each participant user i firstly checks the CS, then decides the downloading operation via cellular which can be characterized by a sequence:

$$S_i = \{S_i^m(f_j^k) | m = 1, 2, ..., |S_i|; k \in \{1, 2, ..., |f|\}\}, \tag{1}$$

where m is the downloading sequence number, f_j^k is the *k-th* chunk of f requested by requester user j and $S_i^m(f_j^k)$ denotes the participant user i will download f_j^k in *m-th* order for requester user j while f_j^k is not cached. $S_i^m(f_j^k)$ includes the associated information of f_j^k, and we can rewrite $S_i^m(f_j^k)$ as a tuple: $S_i^m(f_j^k) = (f_{S_i^m}^k, r_{S_i^m}^c, t_{S_i^m}^s, t_{S_i^m}^e)$, where $f_{S_i^m}^k$ is the *m-th* downloaded the *k-th* chunk of f by participant user i, $r_{S_i^m}^c$ is downloading link rate of participant user i via cellular link, $t_{S_i^m}^s$ is downloading start time and $t_{S_i^m}^e$ is downloading end time.

To make sure $S_i^m(f_j^k)$ can be completely downloaded, namely, the chunk f_j^k is to be downloaded by participant user i in the *m-th* order with the time interval $[t_{S_i^m}^s, t_{S_i^m}^e]$, there is a cellular link capacity constraint:

$$\int_{t_{S_i^m}^s}^{t_{S_i^m}^e} r_i^c(t)dt \geq |f_j^k|, \quad m \in \{1, 2, ..., |S_i|\}. \tag{2}$$

Let $\overline{S}_j$ denote the sequence of receiving chunks in requester user j. As the downloading sequences of all users $S_i, \forall i \in I$, $\overline{S}_j$ can be derived as following:

$$\overline{S}_j = \{S_i^m(f_{j'}^k)|\forall i \in I, j' = j, i \neq j\} \cup C_i = \{C_i(f_{j''}^k)|\forall i \in I, j'' = j, i \neq j\}, \quad (3)$$

where $C_i(f_{j''}^k)$ represents the chunk $f_{j''}^k$ cached by user i. Similarly, the receiving operation of user j can be characterized by a sequence:

$$\overline{S}_j = \{\overline{S}_j^n(f_j^k)|n = 1, 2, ..., |\overline{S}_j|\}, \quad (4)$$

where $\overline{S}_j^n(f_j^k)$ represents the n-th receiving chunk f_j^k by the requester user j from participant user i with the WiFi link rate $r_j^w(t)$. We can also write the $\overline{S}_j^n(f_j^k)$ as a tuple includes the receiving information: $\overline{S}_j^n(f_j^k) = (f_{\overline{S}_j^n}^k, r_{\overline{S}_j^n}^w, t_{\overline{S}_j^n}^s, t_{\overline{S}_j^n}^e)$.

We assume that each request user j receives the chunks of a content by the chunk sequence number. In other words, the requester is to receive the $(k+1)$-th chunk of f after received the k-th chunk of f. It can not improve the Quality of Experience to requesters that receiving the $(k+1)$-th chunk of f is done before receiving the k-th chunk of f. Hence, for the different chunks of same content, f_j^k and f_j^{k+1}, the time constraint can be denoted as follows:

$$t_{\overline{S}_j^{n'}(f_j^k)}^e \leq t_{\overline{S}_j^n(f_j^{k+1})}^s, \forall k \in \{1, ..., |\overline{S}_j| - 1\}; n, n' \in \{1, ..., |\overline{S}_j|\}, n' < n; \quad (5)$$

3.2 User Payoff

The payoff of a mobile user mainly consists of two parts: a utility function capturing Quality of Service (QoS) and Quality-of-Experience (QoE) for data retrieve; and a cost function capturing the user's energy consumption for both data downloading and data transport by D2D.

User Utility. We firstly focus on QoS by the data retrieve time for the requesters and a shorter data retrieve time brings a higher QoS for users. Let $S_j^\dagger$ denote the set of requested content by user j and $S_j^\dagger$ is a subset of $S^\dagger$. Let $t_j(f^1)$ denote the sending time of the request for the first chunk of f by user j. Then we define the $\tau_j(f)$ as the content f retrieve time by requester j:

$$\tau_j(f) = t_{\overline{S}_j^n}^e(f^K) - t_j(f^1), \quad K = |f|, f \in S_j^\dagger. \quad (6)$$

We adopt average content retrieve rate, represented by ξ_j, to express the QoS of requester j. The average content retrieve rate ξ_j is calculated by the Eq. 7.

$$\xi_j = \frac{\sum_{f \in S_j^\dagger} |f|}{\sum_{f \in S_j^\dagger} \tau_j(f)}, \quad (7)$$

A higher content retrieve rate brings a higher QoE for users. Let $U_j(\xi_j)$ represent the utility function of user j, which is formulated as follows [13]:

$$U_j(\xi_j) = log(1 + \theta_j \xi_j), \quad (8)$$

where $\theta_j > 0$ is a user-specific evaluation factor capturing user j's desire for a short content retrieve time. Obviously, $U_j(.)$ is a monotonically increasing function and meets diminishing marginal returns.

Energy Cost. In the CCCMN, energy is a precious resource for mobile users because usually mobile devices are powered by batteries. Such energy cost mainly includes the energy consumption for data downloading by cellular links and data exchange over D2D links (WiFi). In this paper, we consider the energy consumption of requester j for requesting f_j as the total energy consumption of retrieving f_j by participants and requester. Then the total energy consumption of requester user j can be formulated as: $E_j = E_j^c + E_j^w$, where E_j^c and E_j^w denote the energy consumption of requester j and participants by cellular links and by WiFi links, respectively.

When mobile users download the content by cellular networks, the energy consumption is determined by the transmission energy and Radio Resource Control (RRC). The transmission energy is proportional to the length of a transmission; and the RRC protocol is responsible for channel allocation and scaling the power consumed by the radio based on inactivity timers [14].

$$E_j^c = \varepsilon_{tran}^c \sum_{f_j \in S_j^\dagger} \sum_{i \in I} \sum_{f_j^k \notin C_i} \varepsilon_{pow,i}^c |S_i^m(f_j^k)|, \tag{9}$$

where ε_{tran}^c (J/B) denotes the transfer and control energy factor to get data by cellular, $\varepsilon_{pow,i}^c$ indicates the transmit power level of participant i by cellular link.

WiFi on phones typically uses the Power Save Mode (PSM), the cost of maintaining the association is small. When associated, the energy consumed by a data transfer is proportional to the size of the data transfer and the transmit power level [14]. In this paper, we consider the same transmit power level of WiFi for all users.

$$E_j^w = \varepsilon_{tran}^w \sum_{f_j \in S_j^\dagger} \sum_{i \in I} (\sum_{f_j^k \notin C_i} |S_i^m(f_j^k)| + \sum_{f_j^k \in C_i} |C_i(f_j^{k'})|), \tag{10}$$

where ε_{tran}^w (J/B) denotes the transfer energy factor to get data by WiFi. Let η_j denote the energy consumption per unit data, QoE of user j for energy cost can be formulated as follows:

$$Cost_j(\eta_j) = log(1 + \phi_j \eta_j) = log(1 + \phi_j \frac{\sum_{f \in S_j^\dagger} |f|}{E_j}), \tag{11}$$

where $\phi_j > 0$ is a user-specific evaluation factor capturing user j's desire for energy cost. Similar to user utility, $Cost_j(.)$ is a monotonically increasing function and meets diminishing marginal returns.

Problem Formulation. According to the above, we formulate the payoff function of requester j as $W_j = U_j - Cost_j$. We consider an ideal scenario with complete network information in this work, the problem of task assignment in CCCMN system can be formulated as the maximization of all users' payoff:

$$\mathbf{W} = \max_{S_i, \overline{S}_j, i, j \in I} \sum_{j=1}^{|I|} (U_j - Cost_j), \quad s.t. \quad \text{Eqs. 2 and 5.} \tag{12}$$

4 Performance Bound Analysis

4.1 Cached Data

In a period of continuous time $[0, T]$, the proposed crowdsourced system includes $|I|$ users (requesters and participants) and system mobility is considered by the dynamic of I (users increase or decrease). Let P^I, $0 \leq P^I < 1$, denote the probability of users dynamic, and the number of users in the time interval $[0, T]$ can be bounded as $|I|(1 - P^I) \leq |I| \leq |I|(1 + P^I)$. Furthermore, the total cache size of all users, denoted by $|\hat{C}|$, is bounded as following:

$$|\hat{C}^\dagger| = \sum_{i=1}^{|I|(1-P^I)} |\hat{C}_i| \leq |\hat{C}| \leq |\hat{C}^\ddagger| = \sum_{i=1}^{|I|(1+P^I)} |\hat{C}_i|, \tag{13}$$

where $\hat{C}_i$ represent the cache resource of user i, $|\hat{C}_i|$ indicates the size of $\hat{C}_i$, $\hat{C}^\dagger$ is the lower bound of $\hat{C}_i$, and $\hat{C}^\ddagger$ is the upper bound of $\hat{C}_i$.

We assume that the content popularity complies the Mandelbrot-Zipf distribution [15]. Accordingly, the probability of request of each file f, P_f^F, can be calculated as following:

$$P_f^F = \frac{(f + q)^{-\alpha}}{\sum_{f'=1}^{|F|} (f' + q)^{-\alpha}}, \tag{14}$$

where α and q are the parameters of the distribution, and f is the rank of the content file.

Let $|S^\dagger|\beta$, β is proportion rate and $\beta \in [0, 1]$, represent the portion of requested files which are satisfied by the cached data. We consider two extreme cases of caching data of all users: (1) all users cache the most popular files of the catalog F, accordingly there are $|S^\dagger|\beta^\ddagger$ files that can be satisfied by cached data; (2) on the contrary, all users cache the least popular files of F, moreover $|S^\dagger|\beta^\dagger$ files can be retrieved by cached data. $\beta^\dagger$ and $\beta^\ddagger$ are constraint by the $\hat{C}^\dagger$ and $\hat{C}^\ddagger$, respectively. Therefore, we formulate the bound of β as following:

$$\begin{gathered} \beta^\dagger = \sum_{f=L^\dagger}^{|F|} P_f^F \leq \beta \leq \beta^\ddagger = \sum_{f=1}^{L^\ddagger} P_f^F, \\ P^r \sum_{f=L^\dagger}^{|F|} |f| \leq \hat{C}^\dagger \leq P^r \sum_{f=L^\dagger-1}^{|F|} |f|, \quad P^r \sum_{f=1}^{L^\ddagger-1} |f| \leq \hat{C}^\ddagger \leq P^r \sum_{f=1}^{L^\ddagger} |f|, \end{gathered} \tag{15}$$

where $\beta^\dagger$ and $\beta^\ddagger$ are the lower bound and upper bound of β, respectively. P^r is the parameter of cache non-redundant proportion, $P^r \in (0, 1]$.

Proposition 1. *In a period of continuous time* $[0, T]$, $S^{\ddagger}$, $S^{\ddagger} \subseteq S^{\dagger}$, *is the set of files satisfied by the cached data in the system,* κ *is a constant real number, then the theoretical performance bound of the proportion of* $S^{\ddagger}$ *is bounded by*

$$\kappa \sum_{f=L^{\dagger}}^{|F|} (f+q)^{-\alpha} \leq \frac{|S^{\ddagger}|}{|S^{\dagger}|} \leq \kappa \sum_{f=1}^{L^{\ddagger}} (f+q)^{-\alpha}$$

Proof: Let $\kappa = \sum_{f'=1}^{|F|}(f'+q)^{-\alpha}$, then the proposition can be proved as mentioned above by Eqs. 13, 14 and 15.

4.2 Downloaded Data

The objective of this crowdsourced system is to maximize the system's payoff, in other words, to reduce the completion time of system tasks and minimise the system energy cost. Let T_d denote the data downloading time by cellular links. Since both the total amount of files to be downloaded and the link resources of all users are determined, we may formulate the system completion time, $T_d^{\ddagger}$, in ideal case as following:

$$T_d^{\ddagger} = \frac{\sum_{i=1}^{|I|} \sum_{m=1}^{|S_i|} |S_i^m(f_j^k)|}{\sum_{i=1}^{|I|} \hat{r}_i^c},$$

where the $\hat{r}_i^c$ represents the average cellular link rate of participant i and $T_d^{\ddagger} < T$.

Actually, it is hard to complete all the downloading task in time $T_d^{\ddagger}$ in practice because that the smallest download unit is chunk and $|S_i|$, $\forall i \in I$, is an integer for each user. Let γ_f represent the chunk size of file f which is decided by content providers.

Proposition 2. *If* $\forall f \in F, \gamma_f \rightarrow 0$, *then we have* $T_d = T_d^{\ddagger}$. *Let* $T_d^{\dagger}$ *be the completely downloading time for all chunks* $S_i^m(f_j^k)$, $\forall i \in I$, *with chunk size* $Z\gamma_f, \forall f \in F$, Z *is an integer, then* $T_d \geq T_d^{\dagger}$.

This proposition can be proved by showing that with infinitely small chunk sizes $\gamma_f \rightarrow 0$ in proposed the crowdsourced system, we can assign the downloading task to each participant based on her/his cellular link rate $\hat{r}_i^c$ and guarantee that all users complete downloading task at the same time $T_d^{\ddagger}$. Any downloading operation under chunk sizes $Z\gamma_f$, $\forall f \in F$, can be equivalently achieved under chunk sizes γ_f, $\forall f \in F$, by the multiple same operations.

4.3 User Payoff Bound

Given a requested content files set $S_j^{\dagger}$ of requester j in a period of continuous time $[0, T]$, there are $|S_j^{\dagger}|\beta_i$ content files can be satisfied by cached data, and $|S_j^{\dagger}|(1-\beta_i)$ content files need to be downloaded by cellular links. Compared to cellular networks, the WiFi transmission bandwidth is larger and more stable via Point to Point communication in short distance, then we assume that all users have the same WiFi link rate r^w and $r^w > r_i^c, \forall i \in I$. Due to $|S_j^{\dagger}|(1-\beta_i)$ content files also need to be transmitted to requester user j[1], then ξ_j can be reformulated as following:

$$\xi_j = \sum_{f \in S_j^{\dagger}} |f| \div (T_{c,j} + T_{d,j}) = \sum_{f \in S_j^{\dagger}} |f| \div (\frac{\sum_{f \in S_j^{\dagger}}}{r^w} + T_{d,j}), \tag{16}$$

where $T_{c,j}$ and $T_{d,j}$ denote the data retrieving time of requester j by WiFi and cellular, respectively. According to Eq. 16, we know that ξ is can be a function of parameter β and T_d. Therefore, ξ can be bounded by:

$$\xi(\beta^{\dagger}, T_d^{\dagger}) \leq \xi(\beta, T_d) \leq \xi(\beta^{\ddagger}, T_d^{\ddagger}) \tag{17}$$

Transmission of the same size of the data, energy consumption of WiFi is much smaller than that of cellular network [14]. Energy cost includes the energy consumption for data downloading on cellular links and energy consumption for data exchange via WiFi. According to Eq. 10, given a $S_j^{\dagger}$ for requester user j, the energy consumption of WiFi is almost constant. Furthermore, E_j is mainly decided by the energy consumption on cellular links. Hence, the energy consumption of all requesters is bounded by:

$$E(\beta^{\ddagger}, T_d^{\ddagger}) \leq E(\beta, T_d) \leq E(\beta^{\dagger}, T_d^{\dagger}) \tag{18}$$

Based on the above, we have the following theorem.

Theorem 1. *Given a proportion rate of cached data β and a set of chunk sizes $\gamma_f, \forall f \in F$, the theoretical performance bound $\mathbf{W}$ is bounded by:*

$$\mathbf{W}(\beta^{\dagger}, T_d^{\dagger}) \leq \mathbf{W}(\beta, T_d) \leq \mathbf{W}(\beta^{\ddagger}, T_d^{\ddagger}) \tag{19}$$

The bound of proposed crowdsourced system is mainly influenced by the proportion rate of cached data β and the chunk sizes $\gamma_f, \forall f \in F$. In future work, we should consider the proportion rate of cached data and the chunk sizes for practical implementation of the proposed crowdsourced content distribution system.

5 Conclusion

In this work, we proposed a CCCMN framework for content distribution, and analyzed the theoretical performance bound of proposed system. The bound of proposed crowdsourced system is mainly influenced by the proportion rate of cached data and the chunk size of each file. Our performance bound analysis is an

[1] Here we ignore the data retrieved by user j herself/himself via the cellular link.

important first step towards the future practical implementation of the proposed crowdsourced content distribution system. It can be a benchmark to study the practical scheduling algorithms and incentive mechanisms for the CCCMN in the scenario without complete network information. Improving the popular data caching ratio and setting a reasonable chunk size are the key factors to enhance the proposed crowdsourced system performance.

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References

1. Jiang, X., Jun, B.I., Nan, G., Zhaogeng, L.I.: A survey on information-centric networking:rationales, designs and debates. China Commun. **12**(7), 1–12 (2015)
2. Ning, Z., Hu, X., Chen, Z., Zhou, M., Hu, B., Cheng, J., Obaidat, M.: A cooperative quality-aware service access system for social internet of vehicles. IEEE Internet Things J. (2017). https://doi.org/10.1109/JIOT.2017.2764259
3. Ning, Z., Xia, F., Ullah, N., Kong, X., Hu, X.: Vehicular social networks: enabling smart mobility. IEEE Commun. Mag. **55**(5), 49–55 (2017)
4. Cisco: Cisco visual networking index: global mobile data traffic forecast update, 2016–2021. CISCO White Paper (2017)
5. Jacobson, V., Smetters, D., Thornton, J., Plass, M., Briggs, N., Braynard, R.: Networking named content. In: Proceedings of the 5th International Conference on Emerging Networking Experiments and Technologies, pp. 1–12. ACM (2009)
6. Su, Z., Xu, Q.: Content distribution over content centric mobile social networks in 5G. IEEE Commun. Mag. **53**(6), 66–72 (2015)
7. Tourani, R., Misra, S., Mick, T.: IC-MCN: an architecture for an information-centric mobile converged network. IEEE Commun. Mag. **54**(9), 43–49 (2016)
8. Lee, J., Jeon, S.: Low overhead smooth mobile content sharing using content centric networking (CCN). IEICE Trans. Commun. **94**(10), 2751–2754 (2011)
9. Han, B., Wang, X., Choi, N., Kwon, T., Choi, Y.: AMVS-NDN: adaptive mobile video streaming and sharing in wireless named data networking. In: 2013 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), pp. 375–380. IEEE (2013)
10. Detti, A., Ricci, B., Blefari-Melazzi, N.: Mobile peer-to-peer video streaming over information-centric networks. Comput. Netw. **81**, 272–288 (2015)
11. Gao, L., Tang, M., Pang, H., Huang, J.: Performance bound analysis for crowdsourced mobile video streaming. In: Conference on Information Science and Systems, pp. 366–371 (2016)
12. Tang, M., Wang, S., Gao, L., Huang, J., Sun, L.: MOMD: a multi-object multi-dimensional auction for crowdsourced mobile video streaming. In: IEEE INFOCOM 2017 - IEEE Conference on Computer Communications (2017)
13. Joseph, V., de Veciana, G.: NOVA: QoE-driven optimization of dash-based video delivery in networks. In: 2014 Proceedings of INFOCOM, pp. 82–90. IEEE (2014)

14. Balasubramanian, N., Balasubramanian, A., Venkataramani, A.: Energy consumption in mobile phones: a measurement study and implications for network applications. In: Proceedings of the 9th ACM SIGCOMM Conference on Internet Measurement Conference, pp. 280–293. ACM (2009)
15. Manaris, B., Vaughan, D., Wagner, C., Romero, J., Davis, R.B.: Evolutionary music and the Zipf-Mandelbrot law: developing fitness functions for pleasant music. In: Cagnoni, S., Johnson, C.G., Cardalda, J.J.R., Marchiori, E., Corne, D.W., Meyer, J.-A., Gottlieb, J., Middendorf, M., Guillot, A., Raidl, G.R., Hart, E. (eds.) EvoWorkshops 2003. LNCS, vol. 2611, pp. 522–534. Springer, Heidelberg (2003). https://doi.org/10.1007/3-540-36605-9_48