Crowdsourcing in ITS: The State of the Work and the Networking

Xiao Wang, Xinhu Zheng, Qingpeng Zhang, Tao Wang, and Dayong Shen

Abstract—**In the last decade, crowdsourcing has emerged as a novel mechanism for accomplishing temporal and spatial critical tasks in transportation with the collective intelligence of individuals and organizations. This paper presents a timely literature review of crowdsourcing and its applications in intelligent transportation systems (ITS). We investigate the ITS services enabled by crowdsourcing, the keyword co-occurrence and coauthorship networks formed by ITS publications, and identify the problems and challenges that need further research. Finally, we briefly introduce our future works focusing on using geospatial tagged data to analyze real-time traffic conditions and the management of traffic flow in urban environment. This review aims to help ITS practitioners and researchers build a state-of-the-art understanding of crowdsourcing in ITS, as well as to call for more research on the application of crowdsourcing in transportation systems.**

Index Terms—**Crowdsourcing, location-based services, network analysis, urban traffic management.**

I. Introduction

CROWDSOURCING was defined as the outsourcing of a job to an undefined group of people through an open call by Jeff Howe in 2005 [1]. After a decade's development, crowdsourcing is now a widely accepted concept, which has been applied in many domains [2]. On the one hand, crowdsourcing shared many common characteristics with Human Flesh Search (HFS) [3], [4], which was literally translated from the Chinese phrase "人肉搜索" (meaning crowd-powered search) [5]. HFS was firstly proposed in 2001 as a new form of task performing mechanism enabled by self-organized crowd-powered search [6] with unique rich online and offline interactions. On the other hand, crowdsourcing and HFS are two typical forms of Cyber-enabled Movement Organizations (CMOs) [7], which has been greatly flourished with online opinion exchanging, agreement negotiating and task performing. The emphasis of Crowdsourcing is to mobilize crowds' power to collaboratively accomplish tasks.

Existing research pointed out that a clearly defined goal or utility function could enable crowds' behavior with higher effectiveness [8]–[12]. In addition, participants' position in the social network may impact their contribution to the task [13], thus stimulates researches focusing on designing effective crowdsourcing mechanisms by utilizing results from social network analysis. Recently, the mechanism has been applied to improve traditional transportation modes, such as Uber and DiDi. Uber's bidding mechanism for real-time matching of demands and supplies would be a good application [14], [15]. It has revolutionized customers' riding experiences, released fragmentized values, and reconstructed social networks for connection beyond mobility. The task could not be achieved by one computer program, a single person, or isolated groups.

By reintroducing human empowerment into the information producing, perceiving, collecting, processing and disseminating loop, crowdsourcing based ITS applications and services integrate the experiences and knowledge of people without space and time limitations, offering us unprecedented information to understand social needs, and combing services and needs with higher efficiency [16]–[21]. With the fast development and wide application of sensing, computing, and networking technologies, social media, wearable and mobile devices have enabled human to be the most sensitive "walking" and "live" sensors, providing huge volumes of real-time signals for social transportation [16], including real-time human-generated social signals, from drivers' trajectory patterns coordinate to their billing histories, as well as traffic condition related messages from social media sites. These new data sources capture detailed people's daily spatio-temporal information, which can be used for traffic and transportation analytics.

Understanding the popular applications of crowdsourcing in ITS is important for both scholars and practitioners, as the wisdom of crowd is playing a more and more important role in public traffic affairs and social activities both online

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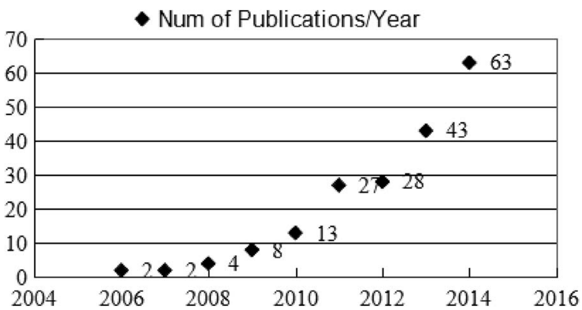

Fig. 1. Number of papers published in this field per year.

and offline. Many researchers have discussed the key insights of crowdsourcing mechanism, the challenges in developing crowdsourcing based systems or platforms, and the evaluation of participators' contribution [14]–[16], [22]–[25]. However, none of them has either provided a structured review of publications on applying crowdsourcing into ITS, or conducted a systematic analysis of its applications. With a huge volume of publications, the community is still not very clear about the main problems, applications and networks about the existing studies and researchers in this field. To this end, an extensive review of state of the art of literature that shape the field and position of existing researches in the community is conducted. Studies on research focuses, diversity of crowdsourcing based ITS services, and author collaboration patterns are performed. Main challenges are identified and a brief introduction to our future work is given at the end.

II. Crowdsourcing in ITS

Papers published on scientific journals, magazines and conference proceedings indexed by the Web of Science database and the EI village database were collected with a set of keywords including either both "crowdsourcing" and "transportation," or both "crowdsourcing" and "traffic". A semi-automated filtering process was conducted subsequently. Finally, a dataset of 201 papers (42 journal papers and 159 conference papers) published during 2006–2015 (shown in Fig. 1) and contributed by 662 distinct researchers, was collected in this study. The papers were extracted from more than 100 sources. One fifth of them are published in Springer's Lecture Notes in Computer Science (14), IEEE Transactions on Intelligent Transportation Systems (9), World Congress on Intelligent Transport Systems, (6), Transportation Research Record (5), and IEEE International Conference on Mobile Data Management (5).

A. Keywords Analysis

A simple way of monitoring the emergence of new research themes is considering the growing frequency of specific terms within a given research area [26]. By analyzing keywords contained in all collected papers, we obtained a general view of research topics in this field.

1,303 distinctive keywords were captured after the keyword extraction and filtering process. Word Cloud is used to illustrate the occurrence-frequency (OF) of keywords in all extracted

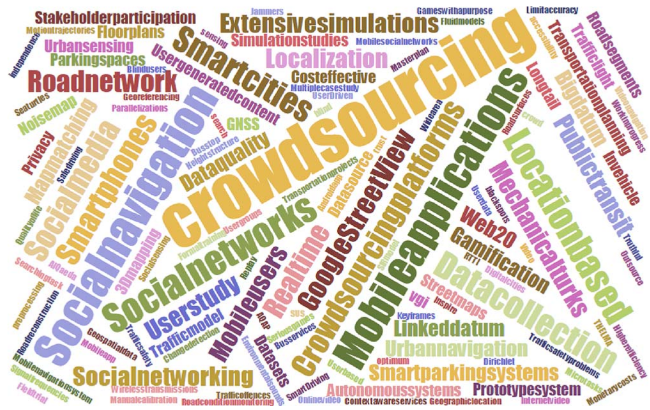

Fig. 2. The Word Cloud of keywords in all papers in our dataset.

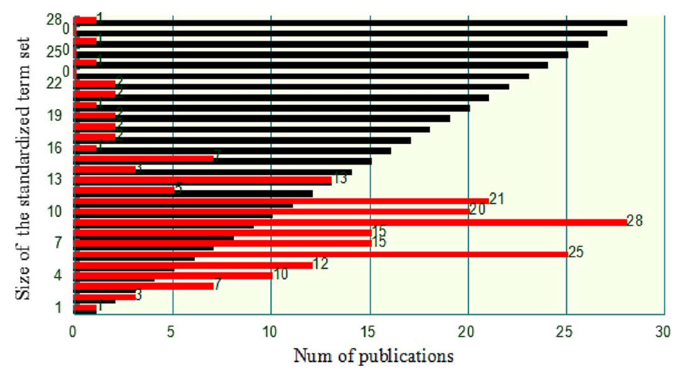

Fig. 3. The distribution of number of keywords in all papers' abstracts. The length of red bars is proportional to the size of the S_Terms set of one article, while the black bars represent the number of papers that cover the corresponded size of S_Term set.

papers (shown in Fig. 2). Keywords with higher OF are highlighted with bigger size. In order to highlight the repeatedly used core keywords and eliminate the least frequently used keywords, the size of *keyword_i* is set to be proportional to the logarithm of OF of *keyword_i* (OF_i), so that keywords with $\mathrm{OF}\_i = 1$ will not be displayed.

From Fig. 2, we observed that the studies on *Mobile applications*, *social networks*, *social navigation* and *location-based* services embedded in *smart phones* attracted great attention. Nowadays, modern smartphones are equipped with a variety of sensors including GPS, accelerometers, WiFi and cellular radios, pressure monitors, light and proximity detectors, cameras, making them ideal collaborative tools for situation sensing and data collection for various tasks. Thus, mobile devices have enabled the integration of technology, systems and societies for transformation in transportation and mobility in the Cyberspace [27], [28]. Amazon's Mechanical Turk (*MTurk*) is a frequently used *crowdsourcing platform*. *Social navigation* in ITS [27]–[34] generally means applying knowledge from social networks, social media sites, or crowdsourcing based mobile applications for path navigation or spot recommendation, which is especially useful for tourists in unfamiliar cities. The term is also used to describe a way of users navigating online through social relation's guidance, and web-robots' cruising behavior with pre-defined paths [35]–[37], which has got rapid

TABLE I
TOP 5 POPULAR S_TERMS AND THEIR MAIN CO-OCCURRENCE TIES

S_Terms	Degree	Top 1 CoF Neighbor (CoF)	Top 2 CoF Neighbor (CoF)	Top 3 CoF Neighbor (CoF)
Crowdsourcing	743	Mobile Applications (12)	Smart Cities (7)	Intelligent transportation systems (6)
Social Navigation	137	Social Networks (5)	Road netwok (3), Social Networking (3)	Location-Based (2), Information Services (2), Privacy (2)
Mobile Applications	113	Road network (12)	Location media (3), Peer-to-Peer system (3), Mechanical turks (3)	Mechanical turks (2), Collaborative interfaces (2), Big datum (2), Planning algorithms (2)
Data Collection	110	Crowdsourcing (4)	Intelligent Transportation Systems (3)	Traffic model (2)
Social Networks	101	Social navigation (5)	Location based (3)	Road network (2), Collective intelligence (2), Social networking (2), Vehicle navigation system (2)

development with advent of the crowd sourced recommendation [38], [39]. In addition, volunteered geospatial information facilitated *location-based* and *task-based* ITS services are getting more and more attention with the help of *Google Street View*.

Keywords used in academic papers are specific-domain oriented standardized technical terms (such as acceleration lane, stop and go events, approach grade), while the combination of keywords can be applied to represent more complicated concepts in various research themes. However, we found that many conference papers do not have a keywords set. Nonetheless, all the papers have an abstract, including a brief introduction of their works, contributions, and applications of their work with the specific-domains oriented standardized terms (S_Term). In general, publications of the same field share more S_Term in their abstracts. Thus we focused on the abstract of all papers and use the extracted 1303 keywords as the complete S_Term set, to identify the S_Term set included in each paper's abstract. The distribution of the number of S_Terms in each paper is shown in Fig. 3. Most papers have only 4 to 13 keywords. Only one paper contains 28 keywords in its S_Term set while 11 papers cover less than 4 keywords. On average, one paper has 9.3 keywords in its abstract.

We introduce social network analysis into keyword co-occurrence analysis in S_Term sets to further help illustrate how keywords are organized and how research themes are formed, thus uncovering trends of researches in the field [42]–[45] (see Table I). Keywords are represented as nodes, and a link is built if two keywords share the same S_Term set. Fig. 4 demonstrates the edge-construction mechanism of the keyword co-occurrence network. Finally, a network of 1,303 keywords (nodes) connected by 7,620 co-occurrence edges is formed.

The keyword co-occurrence network is strongly connected with 10 components. The largest connected component includes 1138 keywords. The rest 165 keywords are in the 9 small isolated components. The average clustering coefficient C of the largest connected component of keyword co-occurrence network is 0.935, with a diameter D of 6. The network density is 0.009, indicating that the network is highly populated with edges. In addition, the network centralization is 0.474, which indicates that the words and expressions used in this field are very diverse and distribute. Fig. 5 presents part of the parameters of the keyword co-occurrence network. We used

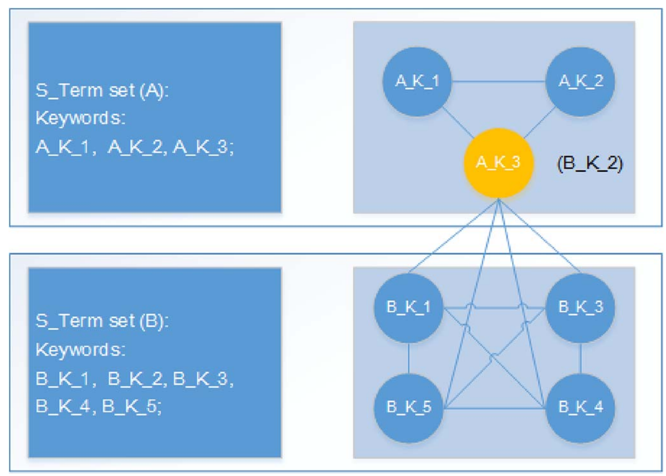

Fig. 4. The diagrammatic sketch of how to construct the keyword co-occurrence network. Keywords are represented as vertices. A pair of keywords are connected if they appear in the same S-Term set. A_K_3 (B_K_2) is a bridge vertex which connected publication A and B together.

Cytoscape to calculate these metrics, and visualize the results and networks in Fig. 5.

The relationship between *average neighborhood connectivity* and *number of neighbors* of keywords is illustrated in Fig. 5(a). The average neighborhood connectivity of a node is defined as the average of number of neighbors of this node's neighbors [3]. It can be inferred that the *average neighborhood connectivity* of keywords with less neighbors is much higher than keywords with more neighbors, as a result that keywords of less neighbors are specifically used in one paper and are more likely to form full connected groups. Keywords with high degree play the role of "bridges" that link different groups of keywords together.

Fig. 5(b) shows the relationship between the network *Topological coefficient* and the keywords' *number of neighbors*. The topological coefficient is a relative measure for the extent to which a node shares common neighbors with other nodes. The edges become more and more concentrated as vertex's degree increases, depicting the high asymmetry of node's shared neighbors in this network.

We have also studied the degree distribution of the keyword co-occurrence network (shown in Fig. 5(c)), and the relationship between *Avg. Clustering Coefficient* and *number of neighbors* of keywords (Fig. 5(d)). The degree of a node

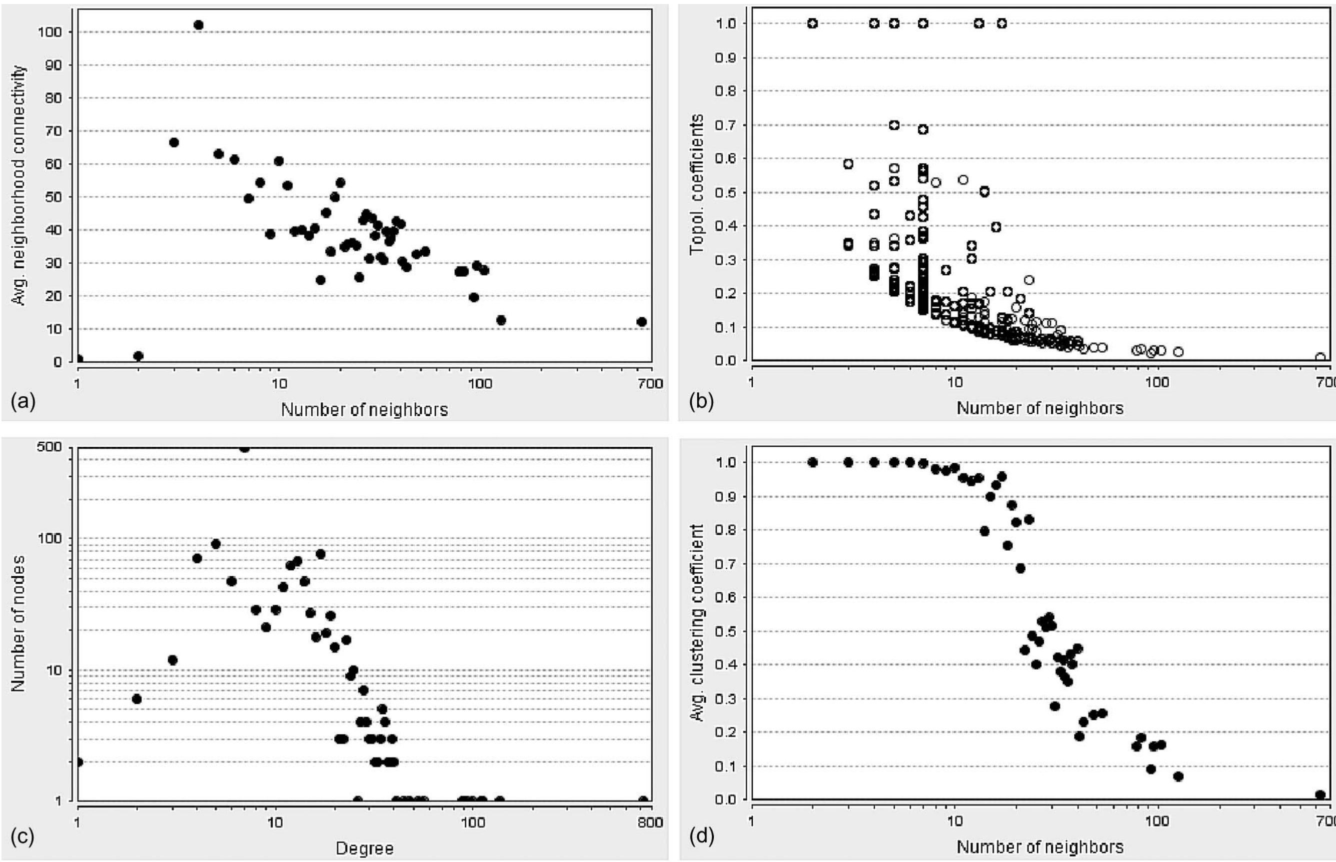

Fig. 5. The neighborhood connectivity distribution (a), topological coefficients (b), node degree distribution (c) and average clustering coefficient (d) of the keyword co-occurrence network.

is measured by the number of links connected to it. *Average clustering coefficient* measures the extent to which nodes in a network tend to cluster together. Fig. 5(d) shows that the *clustering coefficient* of keywords with smaller number of neighbors are much higher than keywords with larger number of neighbors, which indicates that the keywords with smaller number of neighbors are used in specific situations with fewer research focuses.

B. Diversity of Crowdsourcing Based ITS Services

According to the keywords analysis results, crowdsourcing mechanism has been used in various aspects of transportation services. In this part, we identified seven kinds of main services that attracted most attention of the research communities in this field, through theme clustering using the above keywords analysis results. There are also studies focused on other aspects of crowdsourcing based ITS services, however, these studies are very few. We would also give a brief introduction to the other crowdsourcing based ITS services at the end of this part.

Crowdsourced geospatial data (CGD) collection has become a very popular trend with the extensive usage of user-generated content [46]–[49]. CGD is contributed by non-expert end-users for altruistic reasons, which both fully utilizes end-users' significant local expertise and provides better data and temporal coverage [21], [22], [42]. Kanhere [22] presented an investigation of utilizing crowdsourcing data in urban spaces, mentioning that the data can be used for road and traffic condition monitoring while providing no further discussions. Researches in [47]–[49] considered the quality of the volunteered geospatial data, and analyzed its significance especially for monitoring or predicting bus or user motion trajectories. A smartphone based mobility sensing system called *UrbanMobilitySense* was presented in Paper [49]. The system considered both energy consumption of smartphones and user privacy preservation, and had been deployed in Singapore to support the Land Transport Authority's transportation activity surveys. Reference [21] proposed a crowdsourcing solution for public transit data collection called *CommYouTer*, which was able to track the user's location and activity via taking advantage of GPS antenna and accelerometer embedded inside of the smartphones. The application of communication infrastructures (such as WiFi access points, 4G services) for participatory sensing to generate real-time traffic statistics was depicted in [22]. It performed well to collect pedestrian generated street-level audio samples and creating citywide noise map. However, because CGD mainly comes from self-organized communities without credit check and guarantee of the quality, the reliability of CGD has become an important issue that need to be further addressed.

Road condition monitoring and assessment [50]–[64], with advancement of social media sites like *Facebook*, *Twitter*, *YouTube*, and *Flickr*, has gained great popularity recently, particularly in developing countries, as it enables people to effectively participate in solving the time spatial critical traffic tasks without generating additional financial burden on the transportation agencies. Road hazard reporting applications such as *Citizens Connect*, *Fill That Hole*, *seeClickFix* and *CityCare* have stimulated strong interests from many governments to develop ways of harnessing the wisdom of crowds. A crowdsourcing based mobile application named *CommuniSense* allows users to locate, describe, and photograph road hazards and to evaluate Nairobi's road quality information is presented in paper [51]. The collected road hazard reports are then verified using *MTurk*. Authors in [52], focused on the potential of incorporating crowdsourcing techniques into the compilation procedure of cadastral maps, thus to capture citizens' intention and to evaluate current official cadastral processes in depth. Koch *et al.* [55] designed a road surface pavement monitoring framework to detect patches in images taken from vehicles' parking camera. Paper [11] introduced another crowdsourcing based road surface monitoring system called *CRSM*, which effectively detect road potholes and evaluate road roughness levels using GPS devices and low-end accelerometers. It worked via transmitting potential pothole information to a central server, thus provides a comprehensive evaluation on road surface quality. Other means of monitoring and assessing road condition include developing mobile applications by interfacing to existed geospatial/image/video systems [56]–[61].

Urban traffic planning and management is one of the biggest challenges for speeding up the urbanization and building smart cities. Urban traffic related studies [11], [14], [27], [57], [61], [64]–[67] focused on bus arrival time prediction, common trajectory pattern identification, shortest-path computing, optimal route planning, customized deployment of cycle length and signal transition time of Traffic Light Systems, travel information recommendation, to name but a few. Nandan *et al.* [23] conducted an extensive review of publications and applications applying mobile crowdsourcing mechanism to public transportation management, and briefly introduced the designs for collaborative riding, GPS data collection, and bus arrival time prediction. A robust trajectory estimation scheme called *TrMCD* was designed in paper [48], which worked well for alleviating the negative influence of abnormal crowdsourced user trajectories and overcoming the challenges resulted from spatial unbalance of crowdsourced trajectories, by employing statistical results of trajectory information in trajectory-dense area. Studies in paper [56] designed a system for blind transit riders. By using mobile devices to detect crowdsourced landmarks around bus stops, the system identified how blind riders' accesses to landmarked information affects the application into public transportation. Chuang *et al.* [14] developed methods to detect the "stop and go" events of vehicles to adjust the cycle lengths and signal transition time in traffic light systems. A shockwave technique was applied to collapsing the stop and go events over multiple signal cycles into one and calculating Phase Timing Information based on crowdsourcing method by taking advantage of smart phone provided computing power. Besides, a three-phase spatio-temporal traffic bottleneck mining (STBM) model was developed in [27]. The model used location-based data to spatially and temporally discover STB in urban networks, which had been implemented in a taxi dispatching system in Taiwan. The model worked well on alleviating congestion and improving the performance of traffic networks. Authors in [66] proposed an innovative approach which allowed riders to assist the central transit system on decentralized scheduling and dispatching with dynamic scheduling and higher efficiency by using crowdsourcing applications on smartphones. Works in paper [67] investigated the question of how to detect relevant events such as traffic accidents, jams, service interruptions in urban environments via monitoring the Twitter accounts of urban transport operators.

Green transportation has attracted great attention from researchers, economists and officials worldwide. Using crowdsourcing based mobile applications, green transportation aims to reduce fuel consumption and carbon emission, and to provide a high efficient trip mode for both public and private transports. It has been successfully applied to many vehicular application scenarios, including *Social Drive* [67], *UbiGreen* [68], *Cyberphysical bike* [69], *GreenGPS* [70], *HyDi* [71], etc. In the context of Internet of Things (IoT), the communication of vehicles to vehicles, websites, people, and infrastructures has become a reality. The knowledge generated by social interactions can help to improve the performance of the whole traffic system with less energy consumption, carbon emission and better collaboration. For example, *SocialDrive* is able to provide drivers' awareness of their driving behaviors with regard to the fuel economy of specific trips. *Cyberphysical bike* [69] augments bicycles with video processing and computational capabilities, so that they can be used to continuously monitor the environment behind the biker, to automatically detect rear-approaching vehicles, and to alert the biker. *GreenGPS* [70] is a navigation service using participatory sensing data to map fuel consumption on city streets, thus allowing drivers to find the most fuel efficient routes for their vehicles between arbitrary end-points.

Social navigation leverages public online information with users' social network resources, providing real time exploration in novel and strange environments [28], [29], [31], [71]–[76]. Alexandros *et al.* [25] considered the utility of traffic network. The authors stated that smartphones provided us with not only data collection function but also their computing and storage resources, thus parallel approaches could be applied to split the fast changing road networks into chunks of data that can be processed separately. The idea was then applied to a navigation service embedded in mobile applications that was able to provide feasible solution whenever a user requested a route. A different research presented in [36] discussed the use of social navigation paradigm as a way of organizing visual displays of cruising system action. Meanwhile, studies in [75] stressed the significance of social navigation in enabling the emergence of collaboration between individual strangers. The mobile system prototype proposed by Bilandzic *et al.* [73] offered an easy way of seeking information for new residents or visitors, so that they could access tacit knowledge from local people, and could receive help to navigate in unfamiliar urban environment. Considering real-time data regarding weather, traffic, specific driver patterns and other social signals, Altman *et al.* [28] presented a method that was able to optimize navigation utility toward travel cost, route uniqueness, and reduce risk of adverse events. Because tourism occupied a large proportion in the urban economy of many cities, facilitating tour spot and circuit recommendation become the core concerns for urban management. Therefore, Tiwari *et al.* [77] considered both the social tagged geospatial data and the proactively-generated users' opinions and perspectives, and developed a location recommend system called TSRS (Tourist Spot Recommender System).

Smart parking is another long-standing problem in ITS, because searching for street parking and navigating to it in a crowded urban area impose great societal and environmental challenges [18], [78]–[81]. Chen *et al.* [18], [78] simulated the situations when applying different crowdsourcing mechanisms to a smart parking system, and pointed out that the crowdsourcing system could boost social welfare by allowing more free riders to use the service. Paper [24] designed a mobile application called *iParking*, whose effectiveness was proved in a shopping mall. It connects multiple parties such as users, parking facilities and service providers together in a distributed architecture to give more precise parking location information. Authors of [79] also emphasized the importance of real-time communications for parking operators, end users, and parking controllers. They worked together and provided accurate information about available parking area by encouraging users to share their knowledge about parking occupancy, thus to avoid unnecessary cruising. Studies in [24], [80], [81] focused on predicting the availability of parking spaces. Paper [80] detected unparking events by tracking the drivers' trajectory, and predicted the availability of parking space by applying the crowdsourced data to a pedestrian dead reckoning system. Research presented in [24] developed an application for detecting arrivals and departures of drivers by leveraging existing activities recognition algorithms. The framework proposed in paper [81] focused on using fuzzy logic forecast models to estimate the uncertainty of parking availability during the peak parking demand period.

Traffic network construction and communication with ubiquitous roadside units (RSU) and vehicular ad hoc network integrates the capabilities of new generation wireless networks and provides infrastructural support of inter-vehicle, vehicle-to-roadside, and inter-roadside communications in hybrid VANETs [82]–[84]. Wu *et al.* [82] proposed a routing switch mechanism based on crowdsourcing framework which was able to guarantee the quality of data dissemination under various network connectivity and deployment configurations. Bakillah *et al.* [81] introduced the concept of collaborative routing and designed an architecture for exploiting Big Volunteered Geographic Information (VGI), and proposed methods to optimize routing and communication services with higher efficiency. Authors of [84] studied the crowdsourcing based network communication from another perspective of less consumption, and optimize mobile devices' energy efficiency by utilizing signal strength traces reported/shared by other users/devices in cellular networks.

A recent study applied crowdsourcing mechanism into autonomous driving for data collection and 3D road map construction, and developed an architecture called *Driveseat* [85]. In *Driveseat*, crowds make contributions to 1) collecting complex 3D labels and 2) tagging diverse scenarios for ready evaluation of learning systems. Other studies of crowdsourcing based ITS services include how to use crowdsourcing mechanism to estimate the comfort or compatibility of roadways for bicycling [86], how to collect environmental light pollution data by untrained volunteers [87], and how to apply crowdsourcing mechanism into indoor navigation to collect building's architectural details so as to construct the building's 3D models [88].

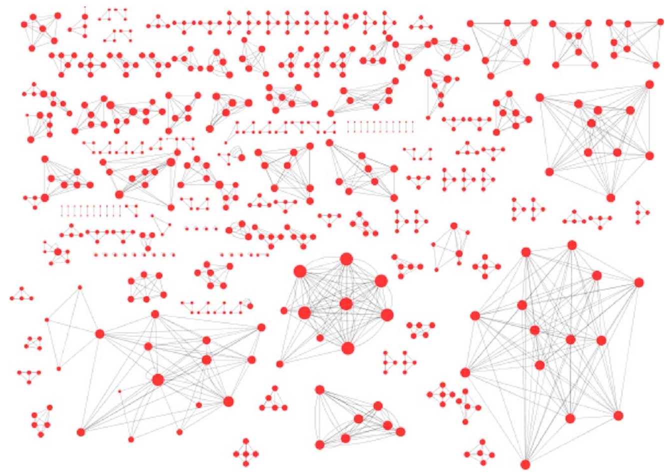

Fig. 6. Coauthor network of publications of crowdsourcing in ITS.

C. Author Collaboration Networks

A co-author network can be seen as a mapping of collaborative times and interaction between researchers within the same research field [89]. Social network analysis is commonly used to explore the structure of all kinds of academic collaboration or social interaction patterns [90]–[94].

It is of vital importance to analyze the author collaboration pattern because it helps understand how scientific knowledge flows among researchers of similar interests and how research communities are organized cross affiliations. Collaborators may function as academic resources to each other by catalyzing their collaborative ties within the network of joint publications. For example, researcher A may directly have links with other researchers, or indirectly know B who has collaborated previously with researcher C, who has the crucial knowledge or skill which is crucial to complete A's research.

In a coauthor network, two authors are linked together if they have collaborated on at least one paper, which depicting the interaction patterns of researchers in one field and identifying those active internationally-recognized collaborating groups. Pairs of researchers have no record of coauthorship will not be linked. Afterwards, we get a network of 662 coauthors connected by 1,441 collaborative edges as Fig. 6 shows.

The collaboration pattern depicted in Fig. 6 reveals that the research groups of applying crowdsourcing to ITS are quite decentralized and isolated. Although researches of applying crowdsourcing to solve traditional ITS tasks, such as real-time geospatial data collection, traffic planning, indoor navigation, have been greatly stimulated in recent years, the collaboration on this emerging new field is still very sparse up to now. 662 coauthors are divided into 165 components, with only a few authors published more than one paper, failing to make a heavy-tail or power law degree distribution. Generally, the

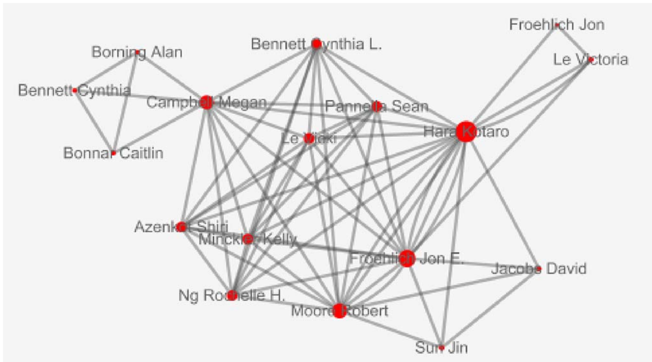

Fig. 7. Coauthor network of publications of crowdsourcing in ITS.

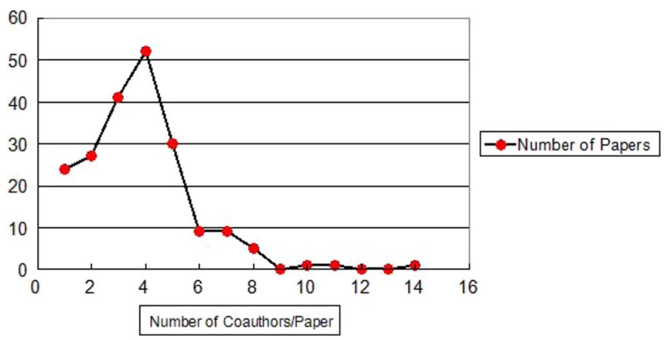

Fig. 8. The distribution of the number of coauthors.

largest connected component of a collaboration network signifies the core mainstream research activity in one research field. The sparsity of collaborative relationship of scholars implies the great development potential in this field.

With all individuals belonging to small isolated components, Hara Kotaro from the University of Maryland made contribution to 5 papers in this field [56]–[61], and he and his collaborators formed the biggest research community in this field (as Fig. 7 shows) with a focus on using *Google Street View* to optimize urban traffic. At the same time, roughly 12% (24 out of 201) of all papers are finished by a single author, while 71 out of 662 (10.7%) authors contributed more than one papers. Generally, the more popular of a topic in a research domain, the more collaboration happens between scholars [95]–[100]. The distribution of number of coauthors in this emerging field is illustrated in Fig. 8. Most papers (174 out of 201) are collaborated by 1 to 5 coauthors, while the average number of coauthors for each paper is 3.74.

III. Challenges

Crowdsourcing based social sharing, interacting and cooperating services have stimulated the enthusiasm of crowds to participate in public affairs. Despite all its merits, it faces great challenges, mainly from network limitation, energy consumption, data quality, data credibility, data accuracy, data privacy, and organization.

Crowdsourcing introduces a more competitive and incentive mechanism to stimulate people's motivation, which proposes higher request for people to be connected online. Thus to fully utilize the social resources and real-time information in cyber space to better complete their tasks. Therefore, network limitation becomes one of the most important constraints, especially for people living in small and medium-sized cities.

Considering many crowdsourcing based services are embedded in smartphones, service running may cost a lot of storage and computing resources. Most location based services need to call GPS applications and compute your nearest resources, which could be very electricity consuming. This fact makes the energy consumption of crowdsourcing based services an urgent problem to be solved.

Crowdsourced data is typically generated in an open and unsupervised environment with few constraints, specifications or quality assurance process. This brings in serious issues regarding the data quality, credibility, accuracy and privacy. Besides, as GPS typically provides an accuracy of up to 10–30 feet, the crowdsourced geospatial data (generated by GPS devices) may fail to give accurate locations. Moreover, some users may generate fake and malicious data to confuse the public, and give wrong guidance or suggestion. New mechanisms need to be developed to address these problems.

Another crucial challenge is how to design better incentive mechanisms to encourage people to join and monitor the crowdsourcing tasks. To this end, both the credibility of consumers and the profitability of service provider need to be ensured, which up to a point supplements the data issues mentioned above.

IV. Conclusion

Crowdsourcing has become an important leverage in today's business, politics and public affair management. Currently, the enabling technologies for real-time collection of social signals have already been available. The next step would be for both engineers and researchers to take the lead in using them for the transformation of intelligent transportation, and for developing new social-physical-cyber systems to realize the construction of smart cities [101]–[105].

Our current research focuses on using geo-spatial tagged data to analyze real-time traffic situation and guide traffic flow with advents of semantic mining, machine learning and probabilistic graphic model technologies. The main challenges lie in three aspects: 1) aggregate data from various kinds of open-sourced sites and target it to specific requests of all kinds of individual drivers; 2) coordinate people coming from different backgrounds with various motivations and behavior patterns for crowdsourcing based traffic analysis platforms; and 3) integrate data, people, location and scene to build artificial scenes, compute the traffic conditions when facing unexpected traffic events, and prescribe with reasonable solutions.

This paper provides a systematic review of state-of-the-art of researches on applying crowdsourcing mechanisms to ITS services. Quantitative analyses of research topics by analyzing the keyword co-occurrence network, crowdsourcing based ITS services, and author collaboration patterns by analyzing the co-authorship network are also performed. In particular, we identify the main challenges and briefly describe our future work. We hope our study could offer new insights to the community of researchers working on applying crowdsourcing mechanisms into ITS.

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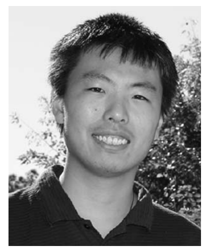

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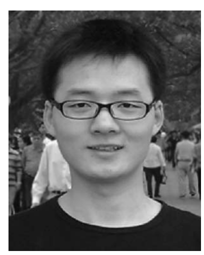

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