IEEE

IoTAIS

PROCEEDINGS

2019 IEEE INTERNATIONAL CONFERENCE ON INTERNET OF THINGS AND INTELLIGENCE SYSTEM (IOTAIS)

5-7 NOVEMBER 2019

Bali, Indonesia

ISBN : 978-1-7281-2516-9
Part Number : CFP19VVK-ART

Sponsored and Organized By :

IoT Center · IEEE ComSoc · Telkom University · Fakultas Teknik Elektro School of Electrical Engineering Telkom University

Supported By :

IEEE Internet of Things · IPv6

COPYRIGHT PAGE

The 2019 IEEE International Conference on Internet of Things and Intelligence System

ISBN : 978-1-7281-2516-9
Part Number : CFP19VVK-ART

Committees of IoTaIS 2019

Steering Committee:

- Dr. Latif Ladid (IEEE IoT Initiative)

Conference Chair:

- Dr. Muhammad Ary Murti (Telkom University, Indonesia)

Organizing Committee:

- Dr. Rina Pujiastuti (Telkom University, IEEE Indonesia COMSOC Chapter)
- Dr. Thinagaran Perumal (Universiti Putra Malaysia)
- Dr. Eng. Asep Suhendi (Telkom University, Indonesia)
- Muhammad Nasrun (Telkom University, Indonesia)
- Casi Setianingsih (Telkom University, Indonesia)
- Ratna Astuti Nugrahaeni ((Telkom University, Indonesia)
- Musrinah (Telkom University, Indonesia)

Technical Program Committee

TPC Chair :

- Dr. Rina Pujiastuti (Telkom University, IEEE Indonesia COMSOC Chapter)

TPC Members:

- Dr. Abdallah Kassem (Notre Dame University , Lebanon)
- Prof. Abdelmajid Khelil (Landshut University of Applied Sciences , Germany)
- Dr. Adit Kurniawan (ITB , Indonesia)
- Dr. Agung Trisetyarso (Universitas Bina Nusantara , Indonesia)
- Prof. Akihiro Yamamura (Akita University , Japan)
- Dr. Alban Duverdier (Centre National D'Etudes Spatiales (CNES) , France)
- Dr. Alessandro Carrega (CNIT , Italy)
- Dr. Alessandro Chiumento (Trinity College Dublin , Ireland)
- Dr. Alexander Wijesinha (Towson University , USA)
- Prof. Ali Abedi (University of Maine , USA)
- Alireza Ghasempour (ICT Faculty, USA)

- Dr. Ángel Andrade (Universidad Autónoma de Baja California , Mexico)
- Dr. Aniket Mahanti (University of Auckland , New Zealand)
- Dr. Anna Antonyová (University of Prešov in Prešov , Slovakia)
- Prof. António Rodrigues (IT / Instituto Superior Técnico , Portugal)
- Dr. Anukram Mishra (Genus Power Infrastructures Ltd, Jaipur , India)
- Dr. Arianna D'Ulizia (CNR , Italy)
- Dr. Arunita Jaekel (University of Windsor , Canada)
- Dr. Ataul Bari (University of Western Ontario , Canada)
- Dr. Athanasios Gkelias (Imperial College London , United Kingdom)
- Prof. Augusto Casaca (INESC-ID , Portugal)
- Prof. Belal Amro (Hebron University , Palestine)
- Prof. Bernd Wolfinger (University of Hamburg , Germany)
- Prof. Besma Smida (University of Illinois at Chicago , USA)
- Prof. Bigomokero Bagula (University of the Western Cape , South Africa)
- Dr. Bogdan Ghita (University of Plymouth , United Kingdom)
- Prof. Bong Jun Choi (Soongsil University , Korea)
- Prof. Carlos Kamienski (Universidade Federal do ABC , Brazil)
- Prof. Carlos Becker Westphall (Federal University of Santa Catarina , Brazil)
- Dr. Cathryn Peoples (Ulster University , United Kingdom)
- Prof. Chengwen Xing (Beijing Institute of Technology , P.R. China)
- Prof. Chih-Shun Hsu (Shih Hsin University , Taiwan)
- Prof. Chuan-Ming Liu (National Taipei University of Technology , Taiwan)
- Prof. Chunguo Li (Southeast University , P.R. China)
- Prof. Constandinos Mavromoustakis (University of Nicosia , Cyprus)
- Prof. Daniel Massicotte (Universite du Quebec a Trois-Rivieres , Canada)
- Prof. Daniel Benevides da Costa (Federal University of Ceara (UFC) , Brazil)
- Prof. Daniele Riboni (University of Cagliari , Italy)
- Dr. David Isern (Universitat Rovira i Virgili , Spain)
- Prof. Deepak Choudhary (LPU , India)
- Dr. Deyun Gao (Beijing Jiaotong University , P.R. China)
- Dr. Dhananjay Singh (Hankuk University of Foreign Studies , Korea)
- Dr. Dimitrios D. Vergados (University of Piraeus , Greece)
- Prof. Domenico Ciuonzo (University of Naples Federico II, IT , Italy)
- Prof. Eduard Babulak (National Science Foundation , USA)
- Prof. Edward Chlebus (Illinois Institute of Technology , USA)
- Prof. Eisuke Kudoh (Tohoku Institute of Technology , Japan)
- Prof. El-Sayed El-Alfy (King Fahd University of Petroleum and Minerals , Saudi Arabia)
- Dr. Eric Renault (Institut Mines-Telecom — Telecom SudParis , France)

- Dr. Erivelton Nepomuceno (Federal University of São João Del-Rei , Brazil)
- Dr. Falah H. Ali (University of Sussex , United Kingdom)
- Dr. Fan Zhai (Huawei Technologies , Hong Kong)
- Prof. Farid Nait-Abdesselam (Paris Descartes University , France)
- Dr. Felix Albu (Valahia University of Targoviste , Romania)
- Dr. Ferkan Yilmaz (Yıldız Technical University , Turkey)
- Dr. Fernando Cerdan (Technical University of Cartagena , Spain)
- Dr. Ferran Adelantado (Universitat Oberta de Catalunya , Spain)
- Dr. Fuad Alnajjar (CUNY – City College of New York , USA)
- Prof. Gaetano Giunta (University of Roma Tre , Italy)
- Dr. Gang Wang (PCTEL, Inc. , USA)
- Dr. George Tambouratzis (Institute for Language & Speech Processing , Greece)
- Prof. Georgios Papadimitriou (Aristotle University , Greece)
- Prof. Gerhard Wunder (Freie Universität Berlin , Germany)
- Dr. Gholamreza Alirezaei (RWTH Aachen University , Germany)
- Dr. Gianluigi Ferrari (University of Parma , Italy)
- Dr. Grzegorz Debita (Wroclaw University of Technology , Poland)
- Dr. Gunawan Wibisono (University of Indonesia , Indonesia)
- Prof. Guy Pujolle (Sorbonne University , France)
- Prof. Hadj Bourdoucen (Sultan Qaboos University , Oman)
- Dr. Haikal El Abed (Technical Trainers College (TTC) , Saudi Arabia)
- Prof. Hamid Alasadi (IRAQ- BASRA , Iraq)
- Prof. Hangsheng Zhao (Nanjing University of Posts and Telecommunications , P.R. China)
- Prof. Hans Schotten (University of Kaiserslautern , Germany)
- Dr. Hari Gupta (Indian Institute of Technology (BHU) Varanasi , India)
- Prof. Harry Skianis (University of the Aegean , Greece)
- Dr. Hing Keung Lau (Hong Kong Institute of Vocational Education , Hong Kong)
- Dr. Huan Zhou (China Three Gorges University , P.R. China)
- Dr. Hugeng Hugeng (Universitas Tarumanagara , Indonesia)
- Dr. Husnu Narman (Marshall University , USA)
- Dr. Hyunbum Kim (University of North Carolina at Wilmington , USA)
- Prof. Igor Kotenko (SPIIRAS , Russia)
- Prof. Igor Bisio (University of Genoa , Italy)
- Dr. Istikmal Istikmal (Telkom University , Indonesia)
- Prof. Jae-Hyun Park (Chung-Ang University , Korea)
- Prof. Jamil Khan (The University of Newcastle , Australia)
- Dr. Javier Prieto (University of Salamanca , Spain)

- Prof. Jeongseok Ha (KAIST , Korea)
- Prof. Jiahong Wang (Iwate Prefrctural University , Japan)
- Prof. Jie Wu (Temple University , USA)
- Dr. Jingjing Wang (Tsinghua University, Beijing , P.R. China)
- Dr. Jinrui Huang (National Laboratory , USA)
- Prof. João Onofre Pinto (Federal University of Mato Grosso do Sul , Brazil)
- Prof. JongWon Kim (GIST (Gwangju Institute of Science & Technology) , Korea)
- Dr. Jongwon Yoon (Hanyang University , Korea)
- Prof. Jörg Franke (FAU Erlangen-Nuremberg , Germany)
- Prof. José Silva (Universidade de São Paulo , Brazil)
- Dr. Josip Lorincz (University of Split , Croatia)
- Dr. Jozsef Vasarhelyi (University of Miskolc , Hungary)
- Prof. Julian Webber (Osaka University , Japan)
- Prof. Junping Geng (Shanghai Jiaotong University , P.R. China)
- Prof. Kai Lin (Dalian University of Technology , P.R. China)
- Prof. Kamran Arshad (Ajman University , United Arab Emirates)
- Prof. Kasturi Vasudevan (Indian Institute of Technology Kanpur , India)
- Dr. Katerina Kabassi (Ionian University , Greece)
- Dr. Kevin Kam Fung Yuen (Singapore University of Social Sciences , Singapore)
- Dr. Khoirul Anwar (Telkom University , Indonesia)
- Prof. Klaus David (University of Kassel , Germany)
- Prof. KyungHi Chang (Inha University , Korea)
- Prof. Lamar Yaoqing Yang (University of Nebraska-Lincoln , USA)
- Dr. Lei Mo (INRIA , France)
- Dr. Lin Cai (Illinois Institute of Technology , USA)
- Dr. Long Chen (Guangdong University of Technology (GDUT) , P.R. China)
- Dr. Lyes Khoukhi (University of Technology of Troyes , France)
- Dr. M. Mustafa Rafique (Rochester Institute of Technology , USA)
- Dr. M. Sajid Mushtaq (University Paris-Est Créteil (UPEC) , France)
- Dr. Marco Chiani (University of Bologna , Italy)
- Prof. Marco Listanti (University of Rome “La Sapienza” , Italy)
- Dr. Marwen Abdennebi (L2TI Laboratory, University of Paris Nord , France)
- Prof. Masahiro Umehira (Ibaraki University , Japan)
- Dr. Maurizio Dusi (NEC Laboratories Europe , Germany)
- Dr. Mauro De Sanctis (University of Rome “Tor Vergata” , Italy)
- Prof. Mesut Günes (Otto von Guericke University Magdeburg , Germany)
- Prof. Mhamed Bakrim (University of Cadi Ayyad Marrakesh , Morocco)
- Dr. Michael Koch (Devolo AG , Germany)

- Dr. Michael Fauß (Technische Universität Darmstadt , Germany)
- Dr. Michele Albano (CISTER/INESC-TEC, ISEP, Polytechnic Institute of Porto , Portugal)
- Prof. Miguel Franklin de Castro (Federal University of Ceará , Brazil)
- Dr. Miguel López-Benítez (University of Liverpool , United Kingdom)
- Prof. Miroslav Voznak (VSB – Technical University of Ostrava , Czech Republic)
- Dr. Mithun Mukherjee (Guangdong University of Petrochemical Technology , P.R. China)
- Dr. Mohamad Mroue (Lebanese University , Lebanon)
- Dr. Mohamed El-Nemr (Tanta University , Egypt)
- Dr. Mohamed Eltoweissy (Virginia Military Institute , USA)
- Dr. Mohammad Rashid (Massey University New Zealand , New Zealand)
- Dr. Mohammed Abdala (AL-Nahrain University , Iraq)
- Dr. Mohammed-Amine Koulali (University Mohammed I , Morocco)
- Dr. Mohd Farhan Md. Fudzee (Universiti Tun Hussein Onn Malaysia)
- Dr. Montree Kumngern (King Mongkut's Institute of Technology Ladkrabang , Thailand)
- Prof. Mort Naraghi-Pour (Louisiana State University , USA)
- Dr. Muhammad Suryanegara (Universitas Indonesia , Indonesia)
- Dr. Muhammad Reza Kahar Aziz (Institut Teknologi Sumatera , Indonesia)
- Dr. N Nasimuddin (Institute for Infocomm Research , Singapore)
- Prof. Nasser-Eddine Rikli (King Saud University , Saudi Arabia)
- Dr. Natarajan Meghanathan (Jackson State University , USA)
- Dr. Nico Saputro (Florida International University , USA)
- Prof. Ninoslav Marina (UIST , USA)
- Prof. Norman Beaulieu (Beijing University of Posts and Telecommunications BUPT , P.R. China)
- Prof. Nuno Garcia (Universidade da Beira Interior , Portugal)
- Prof. Odiel Estrada Molina (University of Informatics Science , Cuba)
- Dr. Oscar Esparza (Universitat Politècnica de Catalunya , Spain)
- Prof. Osvaldo Saavedra (Federal University of Maranhao , Brazil)
- Dr. Pandelis Kourtessis (University of Hertfordshire , United Kingdom)
- Dr. Paolo Crippa (Università Politecnica delle Marche , Italy)
- Prof. Paolo Bellavista (University of Bologna , Italy)
- Prof. Pascal Lorenz (University of Haute Alsace , France)
- Dr. Paul Yoo (Centre for Electronic Warfare Defence Academy , United Kingdom)
- Dr. Paul Mitchell (University of York , United Kingdom)
- Prof. Paulo de Lira Gondim (Universidade de Brasilia , Brazil)
- Prof. Paulo Pinto (Universidade Nova de Lisboa , Portugal)
- Dr. Philippe Owezarski (LAAS-CNRS, France)
- Prof. Pingyi Fan (Tsinghua University , P.R. China)
- Dr. Praneel Chand (Unitec Institute of Technology , New Zealand)

- Dr. Qian Liu (Dalian University of Technology , P.R. China)
- Prof. Qiang Yang (Zhejiang University , P.R. China)
- Prof. Qinghe Du (Xi'an Jiaotong University , P.R. China)
- Rahmat Salam (Telkom University, Indonesia)
- Dr. Rajarshi Mahapatra (IIIT Naya Raipur , India)
- Prof. Rajendra Boppana (University of Texas at San Antonio , USA)
- Dr. Rallis Papademetriou (University of Portsmouth , United Kingdom)
- Dr. Ram Gopal Gupta (Ministry of Information Technology and Communications , India)
- Dr. Ramoni Adeogun (AAU , Denmark)
- Prof. Ray Sheriff (University of Bolton , United Kingdom)
- Dr. Razvan Stanica (INSA Lyon , France)
- Dr. Redha Radaydeh (Texas A&M University-Commerce , USA)
- Prof. Renato Lo Cigno (University of Trento , Italy)
- Prof. Richard Lin (National Sun Yat-sen University , Taiwan)
- Prof. Ridha Hamila (Qatar University , Qatar)
- Prof. Rodrigo Bortoletto (São Paulo Federal Institute of Education, Science and Technology, Brazil)
- Prof. Saad Bennani Dosse (Sidi Mohamed Ben Abdellah University, Morocco)
- Dr. Saad Qaisar (School of Electrical Engineering and Computer Science (SEECS), NUST , Pakistan)
- Dr. Sabu M Thampi (Indian Institute of Information Technology and Management , India)
- Prof. Salahuddin Mohammad Masum (Southwest Tennessee Community College , USA)
- Prof. Salim Bitam (University of Biskra , Algeria)
- Prof. Sang-Kook Han (Yonsei University , Korea)
- Dr. Sanjay Singh (Manipal Institute of Technology , India)
- Prof. Seong-Ho Jeong (Hankuk University of Foreign Studies , Korea)
- Prof. Seung-Hoon Hwang (Dongguk University , Korea)
- Dr. Shao Ying Zhu (University of Derby , United Kingdom)
- Prof. Shashikant Patil (SVKMs NMiMS Mumbai India , India)
- Dr. Shuai Zhao (Tencent America LLC , USA)
- Dr. Shyh-Lin Tsao (Cherry Tree Consulting Co. , Taiwan)
- Dr. Sivabalan Arumugam (Motorola India Research Labs , India)
- Dr. Sofiane Hamrioui (Polytech School, Nantes Universities , France)
- Dr. Soo King Lim (Universiti Tunku Abdul Rahman , Malaysia)
- Dr. Sotiris Karachontzitis (University of Patras , Greece)
- Prof. Stefano Rini (National Chiao Tung University , Taiwan)
- Dr. Sudarshan Guruacharya (University of Manitoba , Canada)
- Prof. Sudharman Jayaweera (University of New Mexico , USA)

- Dr. Suryo Adhi Wibowo (Telkom University , Indonesia)
- Dr. Takashi Kurimoto (NII , Japan)
- Dr. Tariq Umer (COMSATS University Islamabad Wah Campus , Pakistan)
- Dr. Teerapat Sanguankotchakorn (Asian Institute of Technology , Thailand)
- Prof. Terje Jensen (Telenor , Norway)
- Dr. Tetsuya Yokotani (Kanazawa Institute of Technology , Japan)
- Prof. Theodoros Tsiftsis (Jinan University , P.R. China)
- Dr. Theofilos Chrysikos (University of Patras , Greece)
- Dr. Tian Zhang (Shandong Normal University , P.R. China)
- Prof. Tin-Yu Wu (National Ilan University , Taiwan)
- Dr. Tomasz Rutkowski (RIKEN AIP , Japan)
- Dr. Tri Priyambodo (Universitas Gadjah Mada , Indonesia)
- Dr. Tu Nguyen (University of Minnesota, Twin Cities , USA)
- Dr. Vaggelis Kapoulas (Computer Technology Institute and Press–Diophantus , Greece)
- Dr. Vladimir Dyo (University of Bedfordshire , United Kingdom)
- Dr. Watcharapan Suwansantisuk (King Mongkut's University of Technology Thonburi , Thailand)
- Dr. Wei Yuan (Huazhong University of Science and Technology , P.R. China)
- Dr. Wei Zhan (Texas A&M University , USA)
- Dr. Wei Feng (Tsinghua University , P.R. China)
- Prof. Wei Wei (Xi'an University of Technology , P.R. China)
- Prof. Wei-Guang Teng (National Cheng Kung University , Taiwan)
- Prof. Wuyi Yue (Konan University , Japan)
- Prof. Yang Xiao (The University of Alabama , USA)
- Prof. Yatindra Nath Singh (Indian Institute of Technology Kanpur ,India)
- Dr. Yee Wei Law (University of South Australia , Australia)
- Dr. Yi Gai (Intel Labs , USA
- Dr. Ying Zhang (Facebook , USA)
- Prof. Ying-Ren Chien (National I-Lan University , Taiwan)
- Dr. Yoan Shin (Soongsil University , Korea)
- Prof. Yongjun Xu (Chongqing University of Posts and Telecommunications , P.R. China)
- Prof. You-Chiun Wang (National Sun Yat-Sen University , Taiwan)
- Prof. Young-Chon Kim (Chonbuk National University , Korea)
- Prof. Yuan Wu (Zhejiang University of Technology , P.R. China)
- Dr. Zhe Yang (Northwestern Polytechnical University, P.R. China)
- Dr. Zhi Liu (Shizuoka University , Japan)
- Prof. Ziyu Shao (ShanghaiTech University , P.R. China)
- Prof. Zygmunt Haas (Cornell University , USA)

Table of Contents

Paper Titles

IEEE

CERTIFICATE OF APPRECIATION

IoTAIS

2019 IEEE International Conference on Internet of Things and Intelligence System

Bali, Indonesia

November 5 - 7, 2019

This is to Certify that

Bambang Soelistijanto

Actively Participated as Presenter of

"Periodicity Detection of Node Behaviour in Opportunistic Mobile Social Networks"

Sponsored and Organized By :

IoT Center · IEEE ComSoc · Telkom University

Supported By :

IEEE Internet of Things · R6

Dr. Rina Pudji Astuti
Chair of IEEE ComSoc Indonesia Chapter

Dr. Muhammad Ary Murti
Chair of IoTaIS 2019

Periodicity Detection of Node Behaviour in Opportunistic Mobile Social Networks

Bambang Soelistijanto
Department of Informatics
Sanata Dharma University
Yogyakarta, Indonesia
b.soelistijanto@usd.ac.id

Elisabeth Kusuma Adi Permatasari
Department of Informatics
Sanata Dharma University
Yogyakarta, Indonesia
permatasari_erma@yahoo.com

***Abstract*—The recent rise of networks that rely on human mobility, such as opportunistic mobile social networks (OMSNs), has prompted the need for methods that detect the periodic patterns of node movements. Knowledge of the periodicity of node behaviour is essential to design effective and efficient network protocols in such networks. Node behaviour in OMSNs is typically characterized by the node contact patterns. In fact, node connections in these networks occur intermittently, resulting in sparse contact data. Consequently, the traditional periodicity detection methods, e.g. the FFT periodogram and autocorrelation, that favour complete, regularly-sampled time-series data are unsuitable in this setting. In this paper, we exploit the Lomb-Scargle periodogram, initially designed to handle incomplete or irregular sampling data, to identify node behaviour periodicity in OMSNs. Using simulation driven by real human contact traces, we show that the technique is able to accurately detect the behaviour periodicity of majority nodes in the network, even for those with a high level of sparsity contact data.**

Keywords—periodicity detection, sparse contact data, the Lomb-Scargle Periodogram

I. INTRODUCTION

As a natural evolution of mobile ad-hoc networks (MANETs), opportunistic mobile networks (OMNs) [1] have gained popularity in research and industry in recent years. While MANETs require pre-existing paths to enable message transfers, OMNs are able to support communication between pairs of nodes in the absence of stable paths between them. Unlike MANETs that consider node mobility is a potential disruption, message delivery in OMNs relies on unpredictable node contacts, resulting in a higher delivery delay than that of MANETs. Message delivery in OMNs is therefore delay-tolerant in nature. Although other realisations of OMNs exist, human-based opportunistic mobile networks (also referred to as *pocket-switched networks* [2] or *opportunistic mobile social networks* (OMSNs) [3]) are the most prolific. A key factor in the proliferation of these systems is the rapid adoption of mobile devices, such as smart phones, gadgets, and laptops.

In general, the key challenge in OMSNs is choosing the best message carriers to enable message delivery in a high success rate within a short delivery time. By taking a user-centric approach to networking, knowledge of human behaviour and structure can be one of the key information sources for designing effective and efficient routing protocols in OMSNs. For instances, the social-aware forwarding algorithms proposed by Daly *et al*. [4] and Hui *et al.* [5] use two social structure information, namely social-rank (betweeness and degree centralities, respectively) and social-closeness (similarity and community, respectively), as the forwarding metrics to choose the most likely message carriers in the network. Furthermore, it has already been proven that the idea about people moving in a random manner is no longer valid nowadays [6]. Instead, it turns out that human tend to have repetitive behaviour, such as (social) activities that they perform periodically to fulfill their social needs, e.g. going to offices on weekdays or meeting friends in coffee shops on weekends. Hui *et al.* [5], when designing the BubbleRap routing algorithm, divided human daily life into 4 main periods: morning, afternoon, evening, and night – each almost 6 hours. Moreover, Williamson *et al*. [7] argued that considering the periodic patterns of node mobility in making routing decisions can improve the network delivery performance. Indeed, accurately identify the periodic patterns of node behaviour is essential to design more efficient routing algorithms in OMSNs.

There are several methods in the literature that can be utilized to identify the periodicity of time series data, such as the FFT periodogram [8] and autocorrelation [9]. These conventional methods typically favour complete, uniformly-sampled data in time order. However, this requirement is no longer valid in the case of OMSNs. In these networks, node behaviour is commonly characterized by the node encounter patterns. Due to the intermittent contacts in OMSNs, it is difficult to obtain node connection information in each time bin of regularly-sampled time series data. Consequently, the majority of the time bins are filled up with value of '0', resulting in sparse time-series contact data. Moreover, even though the traditional methods are able to detect node contact periodicity, these strategies consume a lot of memory space of OMSN nodes to save a large number of data of '0'. Clearly, this situation is critical in mobile communication networks, since the network nodes possess a very limited storage or buffer capacity. Detection on the periodicity behaviour of nodes in OMSNs is therefore a challenging task.

In this paper, we propose the Lomb-Scargle periodogram [10] to calculate node behaviour periodicity in OMSNs. This technique is a well-known algorithm for detecting and characterizing periodic signals in incomplete or unevenly-

978-1-7281-2516-9/19/$31.00 ©2019 IEEE

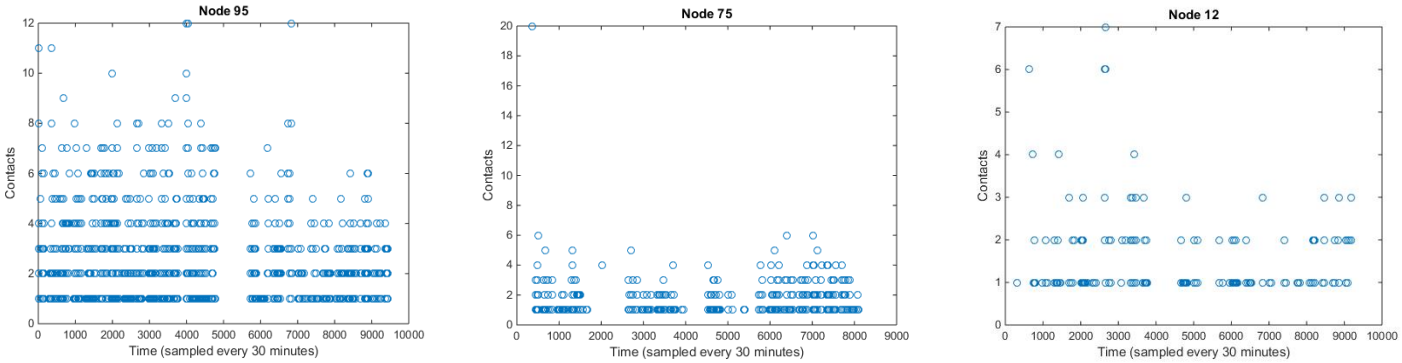

Fig. 1. Reality scenario: Node-contact time bins equally-sampled every 30 minutes

sampled time series data. In our case, however, the Lomb-Scargle periodogram identifies the periodic patterns of sparse, uniformly-sampled time series contact data in OMSNs. Moreover, the time bins with value of 0 can be considered as none (*NaN*) in this algorithm. As a result, these values do not need to be stored in nodes' storage, leading to the significant reduce of the memory usage. In this study, we use two real human contact datasets, namely Reality [11] and Haggle [12]. We consider the former dataset as the long-term mobility case, while the latter as the short-term case.

The rest of the paper is structured as follows. In Section II, we discuss the characteristics of node contact data in real-life OMSNs. Periodogram techniques for detecting the periodicity of time-series contact data is presented in Section III. Subsequently, Section IV describes the performance evaluation of the Lomb-Scargle periodogram compared to the FFT periodogram in detecting node behaviour periodicity in the OMSNs. Finally, Section V concludes the paper.

II. Characteristics of Node Contacts in OMSNs

In this section, we discuss the characteristics of node contact patterns in real-life OMSNs. We consider two real human contact datasets, namely Reality and Haggle. In each dataset, we choose 3 nodes with different level of activeness in the network, e.g. the most active node, moderately active node, and the least-active one.

A. Reality Mining Dataset

The Reality Mining contact dataset [11] captured the activities of students and staffs of MIT during one academic year. There were 97 participants, comprising both undergraduate and postgraduate students and laboratory staffs. The experiment was performed around 10 months at the MIT campus. Using the ONE simulator [13], for each network node we regularly record the number node connections in every a 30-minute time interval. Eventually, this creates uniformly-sampled time-series contact data.

From the dataset, we found that the most active node, node 95, completed 3486 contacts with other nodes throughout the simulation time. However, when the contact data are sampled uniformly in every 30 minutes on the node's connections to the peers, there are more than 85% of the time bins with no connection data. In other words, only 15% of the time-series contact data are available to be used to detect the node's behaviour periodicity. Specifically, we depict in Fig. 1 the records of encounters of node 95, 75 and 12, which represent the most active, quite active, and the least active nodes, respectively, in Reality. The figure shows that the most-active node has the lowest level of data sparsity, roughly 75%. In contrast, the least-active node possesses the highest level of sparsity, namely 97%. In between the two nodes, the quite active node, node 75, has 83% level of data sparsity.

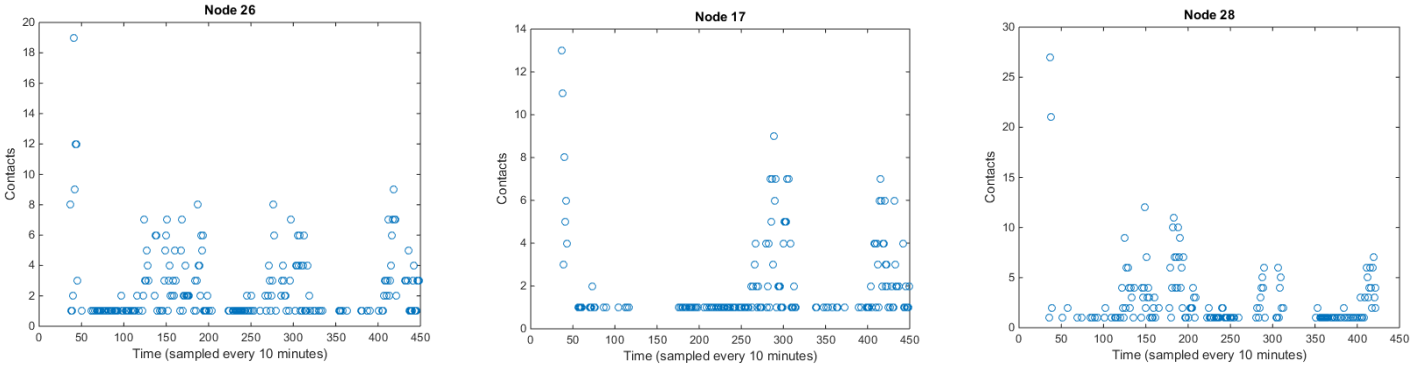

Fig. 2. Haggle scenario: Node-contact time bins equally-sampled every 10 minutes

B. Haggle Infocomm Dataset

The second dataset we consider in this study is Haggle [12], which represents the short-term real human mobility case. This contact trace was taken during IEEE Infocomm 2005 conference in Grand Hyatt Miami participated by 41 persons and lasted for 3 days. For each node in the dataset, using simulation we repeatedly capture the number of node contacts in every a 10-minute time interval throughout the simulation time.

In Fig. 2, we show the records of the number of contacts of illustrative nodes in the dataset, namely node 26, 17 and 28. Node 26 is considered as the most active node in the network. In this node, the missing data of the node contacts in the time bins reach more than 53%. On the other hand, node 17 and 28 have roughly, respectively, 61% and 69% time bins with no connection data, i.e. values of "0".

III. Periodicity Detection Techniques in OMSNs

To identify the periodic patterns of node behaviour in OMSNs, in each node total contacts are recorded into time series data sampled in equally spaced time intervals. Based on the signal processing theory, it is needed to calculate power spectral density (PSD) of any time series data for periodicity detection. To enable this computation, signals from time domain must be converted into frequency domain. The calculated PSD represents the power of its possible frequency. Since the period of a signal is the inverse of its frequency, the dominant periodicity of the signal would be the frequency with the strongest PSD. This spectral analysis method estimation is also known as periodogram.

The widely used periodogram is based on FFT, such as Discrete Fourier Transform (DFT) [14]. The normalized DFT of a sequence $x(n), n = 0,1, \dots, N-1$ can be defined as follows:

$$x\left(f_{\frac{k}{N}}\right) = \frac{1}{\sqrt{n}} \sum_{n=0}^{N-1} x(n) e^{-\frac{j2\pi kn}{N}} \quad (1)$$

X is the DFT of a sequence $x(n)$, where the subscript k/N denotes the frequency captured by each coefficient. To find the dominant frequency, the power of each frequency must be calculated. Finally, the periodogram P can then be calculated as:

$$P\left(f_{\frac{k}{N}}\right) = \left\| X\left(f_{\frac{k}{N}}\right) \right\|^2 \qquad k = 0,1, \dots, \left\lceil \frac{N-1}{2} \right\rceil \quad (2)$$

In the case of OMSNs, uniformly sampling on intermittently node contacts in real-life OMSNs produces sparse time series contact data as previously described in Section II. Since the storage capacity of mobile devices is very limited, it is important to sensibly use the nodes' memory space. We consequently propose to remove all the time bins containing zero contact, resulting in incomplete time series data. As a result, the FFT periodogram is no longer able to identify the periodic patterns of the node's time-series contact data. For such scenario, we instead use the Lomb-Scargle periodogram [10] to detect the periodicity behaviour of OMSN nodes. Lomb-Scargle periodogram is formally defined as follows:

$$P_X(\omega) = \frac{1}{2} \left\{ \frac{[\sum_{n=1}^{N} y(t_n) \cos(\omega(t_n - \tau))]^2}{\sum_{n=1}^{N} cos^2(\omega(t_n - \tau))} + \frac{[\sum_{n=1}^{N} y(t_n) \sin(\omega(t_n - \tau))]^2}{\sum_{n=1}^{N} sin^2(\omega(t_n - \tau))} \right\} \quad (3)$$

where τ is defined as:

$$\tan(2\omega\tau) = \frac{\sum_{n=1}^{N} \sin(2\omega t_n)}{\sum_{n=1}^{N} cos(2\omega t_n)}$$

IV. Performance Analysis of the Periodogram Techniques in OMSNs

In this section, we discuss the performance evaluation of the periodogram methods mentioned in Section III in OMSNs. Initially, we investigate the accuracy of the Lomb-Scargle periodogram with incomplete time series contact data compared to the FFT periodogram with complete data in identifying the periodic patterns of node behaviour in real-life OMSNs, namely the Reality and Haggle human mobility scenarios. Subsequently, we examine the extend of data sparsity level to which the Lomb-Scargle periodogram is still able to work properly.

In Fig. 3, we depict the periodicity detection results of nodes in Reality when the two periodogram techniques are applied. We again consider the three nodes in Reality mentioned in Section II, namely node 95, 75 and 12, which represent the most active, moderately active, and the least active nodes, respectively. We see from the figure that the FFT periodogram is surely able to detect almost the same values of periodicity of all the nodes' behaviour roughly ≈ 7 days, even though they have a different level of activeness in the network. Moreover, this weekly periodicity in the long-term scenario is in line with the findings from some studies in social network analysis [15,16] that human tend to have a weekly pattern in their mobility or social activities. Despite its benefit, however, the FFT periodogram requires complete time series contact data to be able to work accurately. This means that a single node should keep all its encounter data throughout the simulation time, leading to quickly deplete the node's memory space. To address this issue, we then remove the (unnecessary) time series contact data containing values of '0' from the node's memory and next apply the Lomb-Scargle periodogram to identify the node's periodic patterns. From Fig. 3, we notice that the method successfully identifies the behaviour periodicity of node 95 and 75 as high as that of the FFT periodogram, which is a weekly cycle. However, the Lomb-Scargle periodogram is ineffective to detect the periodic pattern of node 12, which is the least-active node in Reality that has the highest data sparsity level at nearly 97%.

We next consider the short-term node mobility scenario in this investigation. Fig. 4 illustrates the detected periodicities of nodes in the Haggle dataset. From the figure, we observe that the Lomb-Scargle periodogram is able to detect node periodicities as nearly accurate as the FFT calculation in node 26 and 17, namely an hour cycle. Obviously, the Haggle dataset captured the human movement during a conference that typically has hourly-scheduled activities. However, as in the Reality dataset,

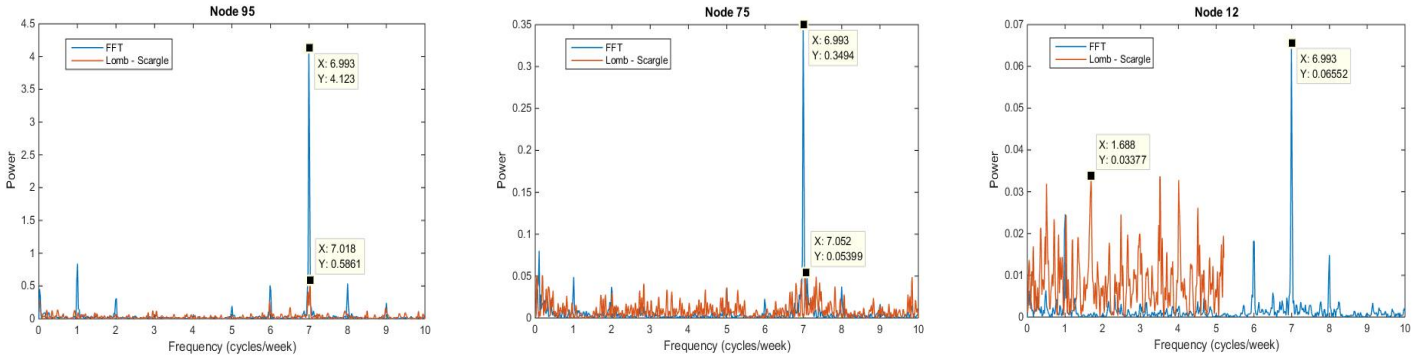

Fig. 3. Reality scenario: node periodicity detection using the FFT and Lomb-Scargle periodograms

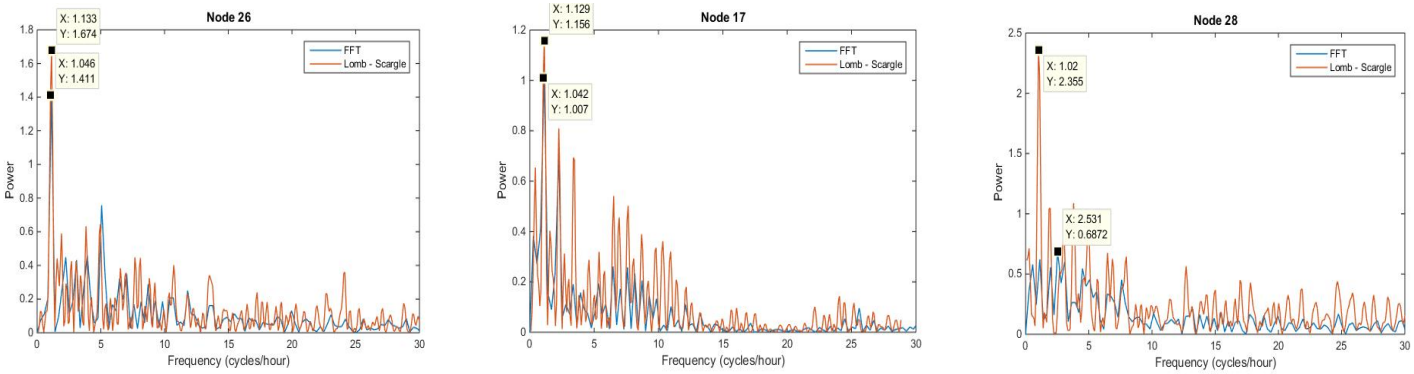

Fig. 4. Haggle scenario: node periodicity detection using the FFT and Lomb-Scargle periodograms

the Lomb-Scargle periodogram is again unsuccessful in correctly detecting the behaviour periodicity of the least-active node in Haggle, node 28, that possesses the data sparsity level at 69%.

Finally, we discuss the performance of the Lomb-Scargle periodogram in real-life OMSNs in terms of the length of contact data traces. As shown above, the length of time series contact data directly affects the upper-bound of data sparsity level where the Lomb-Scargle periodogram is able to work properly. The technique tends to have a better performance if it is applied to long contact data datasets; for example, in Reality the Lomb-Scargle periodogram successfully identifies the nodes' periodic patterns in a higher level of contact data sparsity, around 80% - 85%. On the other hand, in the case of short contact datasets, the algorithm is unsuccessful to accurately detect nodes' behaviour periodicities at a lower data sparsity level: in the Haggle dataset, it fails after the contact data sparsity level exceeds 64%.

In mobile communication networks, such as OMSNs, the memory capacity of mobile devices has become one of the crucial issues. In regard to this, we believe that the Lomb-Scargle periodogram is preferable to be used for detecting node behaviour periodicity in such networks, despite its limitation. Furthermore, to overcome the method's drawback, we argue that the Gossip protocols [17] can be exploited to broadcast a node's periodicity value to all other nodes in the network until they have the same knowledge of the nodes' behaviour periodic patterns. Nevertheless, it needs further study to confirm our idea.

V. Conclusions

In this paper, we have investigated the Lomb-Scargle periodogram for identifying node behaviour periodicity in OMSNs. We consider two distinct real human mobility scenarios, both the long-term and short-term contact data traces. We identify that the Lomb-Scargle periodogram is suitable for calculating node behaviour periodicity in OMSNs, since its accuracy reaches as high as that of the FFT periodogram. In addition, the method is more efficient as it requires less time-series data, leading to save more memory space of OMSN nodes. Furthermore, the Lomb-Scargle periodogram gives more tolerance to the data sparsity level in the long-term mobility scenario. In this case, the method is able to accurately detect the periodicity behaviour of the nodes having a relatively high data sparsity rate.

For future work, we will improve the performance of the Lomb-Scargle periodogram in detecting node behaviour periodicity, particularly in the least active nodes. We also need to investigate the use of the Gossip protocol to distribute node periodicity information to all nodes so that they eventually share the common knowledge of the periodicity behaviour of the nodes in the given network.

REFERENCES

[1] Z. Zhang and R. Khrisnan,"On Overview of Opportunistic Routing in Mobile Ad Hoc Networks", Proc. IEEE Military Comm. Conf, San Diego, CA, USA, 2013, pp. 120-124.

[2] A.K. Pietilainen and C. Diot, "Social Pocket Switched Networks", Proc. 9th INFOCOMM Wkshp, Rio de Janeiro, 2009, pp. 1-2.

[3] B. Soelistijanto,"The Efficiency-Fairness Trade-Off Social-Rank-Based Forwarding in Social Opportunistic Networks, Proc. IEEE Asia Pacific Conf. on Wireless and Mobile, Bandung, 2016, pp. 113-119.

[4] E.M. Daly and M. Haahr, "Social Network Analysis for Information Flow in Disconnected Delay-Tolerant MANETs", IEEE Trans. on Mobile Comp., vol. 8, no. 5, pp. 606-621, 2009.

[5] P. Hui, J. Crowcroft, and E. Yoneki, "BUBBLE Rap: Social-based Forwarding in Delay Tolerant Networks", IEEE Trans. on Mobile Comp., vol. 10, no. 11, pp. 1576-1589, 2011.

[6] T. Hossmann, T. Spyropolous, and F. Legendre, "A Complex Network Analysis of Human Mobility", Proc. INFOCOM Workshops, Shanghai, China, 2011, pp. 876-881.

[7] G. Williamson, D. Cellai, S. Dobson, and P. Nixon, "Self-Management of Routing on Human Proximity Networks", Proc. 6th Intl. Wksp. on Self-Org. Syst., Zurich, Switzerland, 2009, pp. 1-12.

[8] P.D. Welch,"The Use of Fast Fourier Transfom for the Estimation of Power Spectra", IEEE Trans. on Audio and Electroacoustics, vol. 15, no. 2, pp. 70-73, 1967.

[9] M.G. Elfeky, W.G. Aref, and A.K. Elmagarmid,"Periodicity Detection in Time Series Databases", IEEE Trans. on Data and Knowledge Eng., vol. 17, no. 7, pp. 875-887, 2005.

[10] J. D. Scargle, "Studies in astronomical time series analysis. II – Statistical aspects of spectral analysis of unevenly spaced data," Astrophysical Journal, vol. 263, pp. 835–853, 1982.

[11] N. Eagle and A. Pentland, "Reality Mining: Sensing Complex Social Systems", Personal and Ubiquitous Comp., vol. 10, no. 4, pp. 255-268, 2006.

[12] J. Scott, R. Gass, J, Crowcroft, P. Hui, C. Diot, and A. Chaintreau, *CRAWDAD Dataset Cambridge/Haggle/Infocom*, May 2009, (v. 2009-05-29), available: http://crawdad.cs.dartmouth.edu/cambridge/haggle/imote/infocom.

[13] A. Keranen, J. Ott, and T. Karkkainen, "The ONE Simulator for DTN Protocol Evaluation", Proc. 2nd Intl. Conf. on Simult. Tools and Tech., Rome, Italy, pp. 55-62, 2009.

[14] J.O. Smith,"Mathematics of the Discrete Fourier Transform (DFT)", W3K Publishing, 2nd Ed., 2007.

[15] F. Hu, A.F. Smeaton, E. Newman, and M.P. Buman, "Using Periodicity Intensity to Detect Long Term Behaviour Change", Proc. ACM Intl. Joint Conf. Pervasive and Ubiquitous Comp. and Intl. Symp. on Wearable Comp, Osaka, Japan, 2015, pp. 1069-1074.

[16] V. Borrel, F. Legendre, M. Amorim, and S. Fdida, "SIMPS: Using Sociology for Personal Mobility", IEEE/ACM Trans. on Nets, vol. 17, no. 3, pp. 831-842, 2009.

[17] A. Demers, et.al., "Epidemic Algorithms for Replicated Database Maintenance", Proc. 6th Annual ACM Symp. on Principles of Distributed Computing", Vancouver, Canada, 1987, pp. 1-12.