On Seamless Hole-free Virtual Emotion Barrier in IoT-enabled Smart Cities

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***Abstract*—A barrier-coverage is considered as one of promising research branches because it can be used for various applications. Also, thanks to advanced technology in Internet of Things (IoT) environment, human emotion could be recognized by wireless signal. But, the detection accuracy by wireless signal can be different depending on the distance between a person and a device so that there may exist a weak hole with a very low detection accuracy when barriers are formed by IoT devices. In this paper, we introduce a seamless hole-free virtual emotion barrier, which provides the detection of human emotion without the weak hole by virtual emotion barriers. Then, we formally define a problem whose objective is to maximize the minimum detection possibility in the barrier and also propose a novel approach in order to solve the problem. Furthermore, a brief discussion of future work and plan is offered in the paper.**

I. Introduction

Since *emotion* should be an important feature and property of human and interpersonal communication, the emotion recognition has gained lots of attention over the past decades from both academic communities and industry companies including cognitive science, affective computing, medical services, game applications, etc [1], [2], [3], [4].

Moreover, it is anticipated that Internet of Things (IoT) technology will play a critical role in promising smart cities because IoT will provide citizen with rapid and appropriate services based on a large quantity of data including social information, emotion data, economic news, etc [5], [6], [7], [8], [9]. In particular, the emotion detection with possible high accuracy should be one of essential issues for successful realization of smart cities. Such a correct emotion recognition can allow people to receive appropriate services depending on various goals and situations as well as can be utilized for numerous applications such as medical service for sleep disorder, patrol reinforcement, advanced driver assistant systems, etc [10], [11], [12].

In general, human emotion can be recognized by various emotional states based on computational models such as joy, pleasure, happiness, sadness, fear, anger, etc [1], [3]. It is widely known that there are three approaches to extract the information of emotion. Firstly, the emotion can be derived

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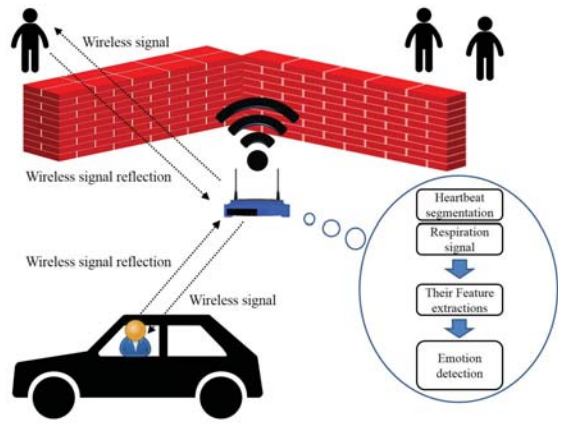


Fig. 1. An example of emotion recognition using wireless signal and its reflection.

from audio and visual information including vocal tone, facial expression, activity [13], [14], [15], [16]. Secondly, it is possible that the emotion is analogized by physiological signals and features by on-body sensors, wearable cyber-physical devices, which returns heart rate, body temperature, blood pressure, etc. [17], [18], [19]. Thirdly, the emotion and gesture derivation by wireless signal recently has been studied in [20], [21], [22], [23]. It is expected that the third approach will be used widely in IoT environment since it has clear benefits of improved privacy, coverage when compared with the aforementioned approaches. Fig. 1 depicts an example of emotion recognition by wireless signal and its reflection. Each IoT device can send the wireless signal to person and receive its reflection. Then, the feature extraction procedures of heart segmentation and respiration signal finally return the derived human emotion. As seen in Fig. 1, wireless signal can pass through walls or other objects. It leads that the identity of the person will not reveal and the sensitive privacy information will not be sent to IoT device because IoT device may need only emotion information of the people if it is used in public area. Definitely, if the private service based on emotion recognition is required, the identity of the person can be applied to the system after agreement of the service user. However, since the emotion or gesture detection accuracy by wireless signal depends on the distance between device and person, this issue should be handled carefully [20], [21].

On the other hand, many researchers have studied *barrier-coverage* because it can be utilized for numerous applications such as public safety, intrusion detection, border surveillance [24], [25], [26]. If we construct a barrier by a set of devices in the region of interest (RoI), the barrier enables at least one device in the barrier to detect any penetration or movement from one section to another location. Thanks to its usefulness, the concept of *barrier-coverage* is considered as one of emerging topics in UAV networks, wireless sensor networks [27], [28], [29], [30], [31], [32]. Specifically, it is highly reasonable that we deliberate on *barrier-coverage* on emotion detection in IoT environment. Kim et al. [33] recently introduced the concept of *virtual emotion barrier* which is able to detect human emotion by IoT device using wireless signal and its reflection. However, there may exist a detection weak point, referred as *emotion detection hole*, if some device in the formed *virtual emotion barrier* has a very low detecting accuracy rate. Also, because the reliability of *virtual emotion barrier* depends on its cumulative accuracy, the issue of solving or minimizing *emotion detection hole* should be addressed importantly.

Based on the above observations, we introduce *seamless hole-free virtual emotion barrier* that is a barrier system in IoT environment. By the proposed system, the emotion of any person moving from one side to another side is to be recognized by at least one IoT device avoiding *emotion detection hole* with a very low detection accuracy when wireless signal is employed. To the best of our knowledge, this is an initial approach to consider *emotion detection hole* in *virtual emotion barrier* research. Furthermore, in this paper, we formally not only define a problem whose objective is to maximize the minimum detection accuracy in the barrier but also represent it using Integer Linear Programming (ILP) formulation. To solve the problem, we propose a novel *Flexible-Emotion-Edge-Selection* approach.

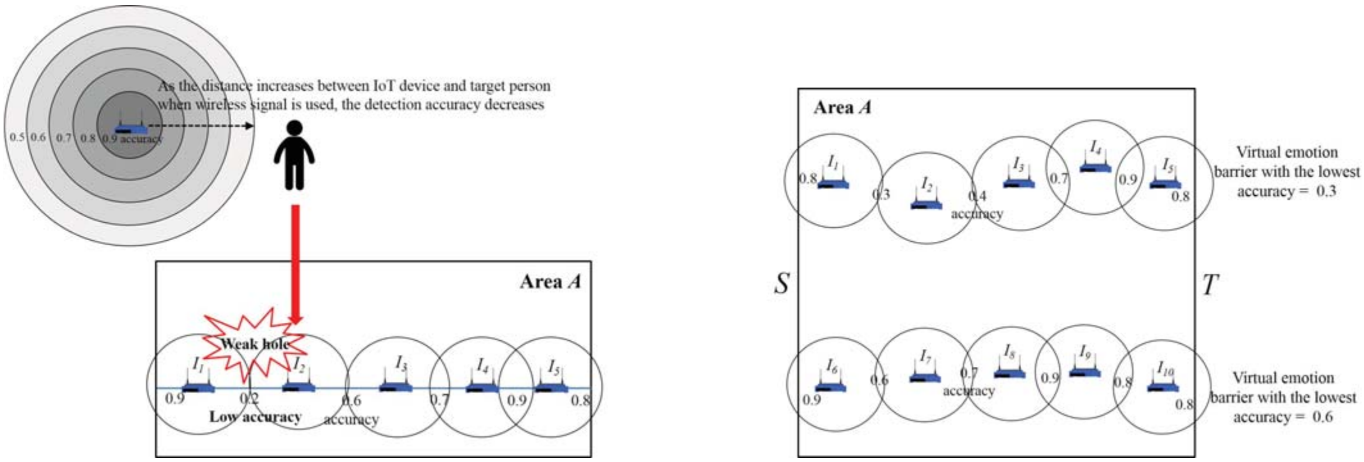
The rest of the paper is organized as follows. The next section reviews several related works. In Section III, we introduce our proposed system for seamless hole-free barrier in IoT environment and formally define a problem with ILP formulation. Then, in Section IV, a novel approach is presented to solve the problem. Finally, we conclude the paper with a discussion of future work in Section V.

II. Related Work

Emotion should be critical factors in human life and communication as it allows to understand intentions of other people. Hence, there are numerous studies related to human emotion within psychology, science, affective computing, etc. First of all, a computational model of human has been considered by [1], [3]. Using a clinical or a medical device, they analyzed the behavior of the emotion computation model toward pursuing the understanding of a human spiritual world. Also, various computation models of emotion were studied in [4], which covers main features of psychological theories. And, in [11], authors devised not only an emotion model for user and group but also multivariate Gaussian scheme and its joint probability to detect some users' unusual emotion status.

Continuously, the research of human emotion has been studied by many researchers. In [14], authors implemented a real time facial expression system through smart phone to extract the human emotion. In [34], Szwoch et al. considered a recognition of emotion using depth channel through Kinect sensor instead of camera. Then, in [35], authors deliberated on a combination of color and depth information through Kinect sensor to derive facial emotion and features. Also, an interactive emotion communication model was proposed to recognize emotion through a biofeedback device in [17] and Agrafioti et al. focused on the study of ECG signal and its psychological features about emotion in [19]. Specially, a promising technology based on wireless signal was introduced for emotion derivation by [21]. In the research, authors also developed the system to evaluate person's heartbeats using wireless signal and its reflection. Then, a useful system for human emotion was proposed by [23], which emotion is extracted from body movements and behavior with a consideration of vehicle with realistic scenario and setting.

On the other hand, there are many studies with various types of applications in the research branch of the barrier-coverage. First, Gage [24] introduced the concept and objective of the barrier-coverage. In [25], [26], Kumar et al. formally defined the concept of k-barrier-coverage in wireless sensor networks, which provides a guaranteed detection of the penetration into the given area. They developed optimal sleep-wake up scheduling schemes to maximize the lifetime of barriers with continuous k-barriers. Then, a study of weak-k-barrier-coverage and lower bound calculation have been done by [27] and Kong et al. [29] defined a new type of problem how to construct a barrier automatically using wireless mobile sensors. Also, in [28], authors devised a new type of barrier, event-driven partial barrier, and considered its resilient construction and maintenance through mobile sensors. Moreover, in [30], [32], authors applied the concept of barrier-coverage to Unmanned Aerial Vehicles (UAV) networks and formally defined a problem how to build reinforced barriers without any conflicts among UAVs when they move from initial spots to specific positions. And, in [31], authors focused on the research how to solve the problem of sensor location errors on the minimum number of mobile sensors and to remove the gap due to those location errors. Besides, a concept of virtual emotion barrier has been introduced by [33]. Authors importantly described the motivation and usefulness of the virtual emotion barrier as well as formally defined a new problem that considers a cumulative accuracy of the barrier in IoT environment.



(a) A relation between IoT device and person for emotion detection accuracy using wireless signal and an example of virtual emotion detection hole.

(b) An example of creating seamless hole-free virtual emotion barrier.

Fig. 2. An example of virtual emotion detection hole and of constructing seamless hole-free virtual emotion barrier.

III. Seamless Hole-free Virtual Emotion Barrier

In this section, we introduce our proposed barrier which is called as *seamless hole-free virtual emotion barrier*. Also, we formally define a problem which we seek to solve in the proposed system.

A. Construction of Seamless Hole-free Virtual Emotion Barrier

In the system, we assume that every IoT device is equipped with wireless signal where the device can derive different types of emotion by procedures including heart segmentation and respiration based on the reflection of wireless signal. Also, suppose that each IoT device has different maximum sensing range. Also, it is noted that the accuracy of emotion recognition decreases as the distance between person and device increases [21].

B. Problem Definition

Now, we define the proposed *seamless hole-free virtual emotion barrier* in the IoT system as follows.

Definition 3.1 (seamless hole-free virtual emotion barrier): Within a given square-shaped area A, we have a set of IoT devices S with a list of different maximum signal ranges R where each IoT device is able to detect emotion within its own sensing range using wireless signal and its refection. A *seamless hole-free virtual emotion barrier (HoF-VEmoBar)* is a barrier that the emotion of any person moving from one side to another side is to be recognized by at least one IoT device without weak hole with a very low detection accuracy possibly.

Then, we formally define the *MaxLoD* problem which is to be solved in the proposed system.

Definition 3.2 (MaxLoD): It is given that a set of IoT devices D are located within A and the detection accuracy information depending on a distance between device and person. Then, the maximum low detection accuracy of emotion (*MaxLoD*) problem is to maximize the low detection accuracy of weak hole in the barrier so as to construct seamless hole-free virtual emotion barrier.

Fig. 2(a) shows a relation between IT device and target person for emotion recognition accuracy through wireless signal and its reflection. By [21], it has been known that the emotion detection accuracy by wireless signal depends on the distance between IoT device and target person. It leads that as the distance increases between the device and the person, the detection accuracy decreases. Also, Fig. 2(a) describes an example of *emotion detection hole*. When a *virtual emotion barrier* is formed by IoT devices consisting of I_1, I_2, I_3, I_4, I_5, the detection accuracy edge between two devices is calculated based on pre-defined accuracy reference. For example, the edge accuracy has 0.9 between I_4 and I_5 in the *virtual emotion barrier*. But, as shown in Fig. 2(a), there exists a weak hole (with a very low edge accuracy 0.2) between I_1 and I_2. Such a weak hole will cause serious problems including the reliability deterioration of the emotion-based system. Hence, the weak hole should be resolved and be considered carefully when *virtual emotion barrier* is built.

Furthermore, Fig. 2(b) represents an example of the proposed barrier type and the defined problem. In the area A, two *virtual emotion barriers* have been found between source S and destination T. One is composed of I_1, I_2, I_3, I_4, I_5 and another consists of $I_6, I_7, I_8, I_9, I_{10}$. As seen in Fig. 2(b), the upper *virtual emotion barrier* has the lowest detection edge accuracy with 0.3 in the barrier. On the other hand, another barrier has 0.6 as its lowest detection edge accuracy in the barrier. Then, we can choose the barrier with 0.6 as *seamless hole-free virtual emotion barrier HoF-VEmoBar)* from the found set of barriers in A.

C. ILP Formulation

We represent *MaxLoD* problem using Integer Linear Programming (ILP). Then, we define the notations which are used in ILP formulation as follows.
n: the number of IoT devices in A.
I: a set of heterogeneous IoT devices, $I = \{I_1, I_2, ..., I_n\}$.
R: a list of signal range of IoT devices, $R = \{r_1, r_2, ..., r_n\}$.
k: an index of IoT device and signal range $(1 \leq k \leq n)$.
j: an index of IoT device and signal range $(1 \leq j \leq n)$.
$\lambda_{k,j}$: accuracy value between I_k and I_j.
μ: the minimum accuracy value in the constructed barrier.

Also, we define integer variables as follows.

$$W_{k,j} = \begin{cases} 1, & \text{if } I_k \text{ and } I_j \text{ are connected by signals} \\ 0, & \text{otherwise.} \end{cases}$$

$$X_{k,j} = \begin{cases} 1, & \text{if } I_k \text{ and } I_j \text{ are selected as a part of } \textit{HoF-VEmoBar} \\ 0, & \text{otherwise.} \end{cases}$$

$$Y = \begin{cases} 1, & \text{if } \textit{HoF-VEmoBar} \text{ is created completely} \\ 0, & \text{otherwise.} \end{cases}$$

An objective function is to maximize the lowest accuracy in the constructing *seamless hole-free virtual emotion barrier*. Then, the objective function is formulated as follows.

$$\textbf{Maximize } \mu \tag{1}$$

Subject to:

$$\sum_{j=1}^{n} W_{k,j} \leq 1, (\forall k) \tag{2}$$

$$\sum_{j=1}^{n} X_{k,j} \geq 1, (\forall k) \tag{3}$$

$$X_{i,j} \leq W_{k,j}, (\forall k, \forall j) \tag{4}$$

$$\lambda_{k,j} \cdot W_{k,j} \cdot X_{k,j} \cdot Y \geq \mu, (\forall k, \forall j) \tag{5}$$

By constraint (2), it is confirmed that two IoT devices I_k and I_j has at most one edge. And, constraint (3) forces that the edge between I_k and I_j is included in *HoF-VEmoBar* at most once. Also, it is imposed that there exists an edge between I_k and I_j in order to choose the edge as a part of *HoF-VEmoBar* by constraint (4). By constraint (5), it is satisfied that μ is the lowest accuracy value when *HoF-VEmoBar* is generated.

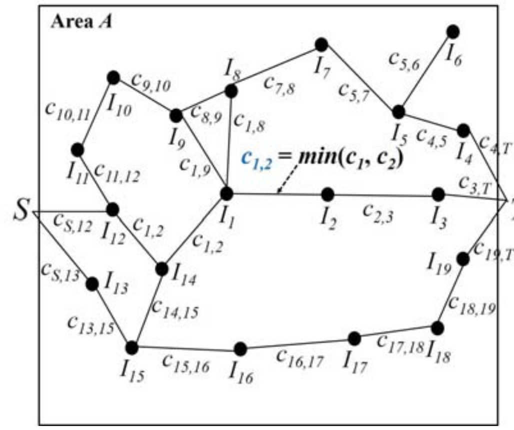


Fig. 3. An example of initial accuracy graph.

IV. Proposed Approach

To solve the *MaxLoD* problem, we propose *Flexible-Emotion-Edge-Selection* approach which returns μ with a construction of *HoF-VEmoBar*. Then, *Flexible-Emotion-Edge-Selection* approach is performed by the below steps.

- Generate a virtual source S and a destination T which are located at two opposite sides of A.
- Each IoT device verifies the neighbors. The neighbor relationship can be decided if *euclidean distance* $Euc(I_k, I_j)$ between two devices is at most a sum of their wireless signal ranges $r_{I_k} + r_{I_j}$ where $I_k, I_j \in S$, $r_k, r_j \in R$, $k \neq j$.
- Create an initial accuracy graph $\mathcal{G}_{\mathcal{I}} = (V(\mathcal{G}_{\mathcal{I}}), E(\mathcal{G}_{\mathcal{I}}))$ where $V(\mathcal{G}_{\mathcal{I}})$ is the set of vertices, $E(\mathcal{G}_{\mathcal{I}}))$ is the set of edges. The set of IoT devices I are added to $V(\mathcal{G}_{\mathcal{I}})$ as vertices and each neighbor relationship between two devices I_k and I_j is put into $E(\mathcal{G}_{\mathcal{I}})$ as an edge $e(I_k, I_j)$, respectively.
- Based on pre-defined accuracy reference according to signal range, calculate a node accuracy value c_k for each IoT device I_k. Then, if the device I_k and I_j are neighbor relationship, the minimum accuracy value of c_k and c_j is assigned as the edge accuracy $c_{k,j}$ of the edge $e(I_k, I_j)$.
- Also, create current status graph $\mathcal{G}_{\mathcal{I}}{}' = (V(\mathcal{G}_{\mathcal{I}}{}'), E(\mathcal{G}_{\mathcal{I}}{}'))$ that is transferred from $\mathcal{G}_{\mathcal{I}}$.
- Then, we do perform the following iterations.
  - From $\mathcal{G}_{\mathcal{I}}{}' = (V(\mathcal{G}_{\mathcal{I}}{}'), E(\mathcal{G}_{\mathcal{I}}{}'))$, choose δ number of the highest accuracy edges e_δ where tho selected edges are connected with at least one of currently selected devices and δ is given as a parameter.
  - Add those e_δ to the set of current barrier candidates B_{cd}. Remove e_δ from $\mathcal{G}_{\mathcal{I}}{}'$.
  - If a completed *HoF-VEmoBar* is found from B_{cd} between S and T, then add edges and vertices of the *HoF-VEmoBar* to B_{HoF}. After searching for the lowest accuracy edge value in B_{HoF} and updating it as μ, return μ.

Algorithm 1 ***Flexible-Emotion-Edge-Selection***

Inputs: A, U, T, I, R, n, δ, Output: μ or $false$

set $\mathcal{G_I}$ = $(V(\mathcal{G_I}), E(\mathcal{G_I})) = \emptyset$;
set $\mathcal{G_I}'$ = $(V(\mathcal{G_I}'), E(\mathcal{G_I}')) = \emptyset$;
set $\mu = \emptyset$;
set $e_\delta = \emptyset$;
set $B_{cd} = \emptyset$;
set $B_{HoF} = \emptyset$;
add U and T to $\mathcal{G_I}$;
find neighbor relationships for every device and add those to $\mathcal{G_I}$;
estimate edge accuracy values for each neighbor relationship and add them to $\mathcal{G_I}$;
set $\mathcal{G_I}' \leftarrow \mathcal{G_I}$;
while $\mathcal{G_I}' \neq \emptyset$ **do**
  select δ number of the highest accuracy the edges e_δ from $\mathcal{G_I}'$;
  $B_{cd} \leftarrow B_{cd} \cup e_\delta$;
  $\mathcal{G_I}' \leftarrow \mathcal{G_I}' - e_\delta$;
  if a completed *HoF-VEmoBar* is found from B_{cd} **then**
    update *HoF-VEmoBar* as B_{HoF};
    find the lowest accuracy edge value in B_{HoF} and update it as μ;
    return μ;
  end if
  if $\mathcal{G_C}' = \emptyset$ and the completed *HoF-VEmoBar* is not discovered **then**
    return $false$;
  end if
end while

– If a completed *HoF-VEmoBar* is not constructed until $\mathcal{G_I}'$ is empty, then return $false$.

Fig. 3 shows an example of initial accuracy graph $\mathcal{G_I}$ = $(V(\mathcal{G_I}), E(\mathcal{G_I}))$. As seen in Fig. 3, there are 19 IoT devices from I_1 to I_{19} in the area A and then those devices are added to $(V(\mathcal{G_I})$ as vertices. Source S and T can be added to $(V(\mathcal{G_I})$, too. Also, based on pre-defined accuracy reference according to signal range, each vertex k has own accuracy value c_k. Then, we need to decide the edge accuracy $c_{k,j}$ of the edge $e(I_k, I_j)$ where the device I_k and I_j are neighbor relationship. For example, in Fig. 3, if c_1 = 0.8 and c_2 = 0.7, then its minimum value $min(c_1, c_2)$ = 0.7 is assigned to $E(\mathcal{G_I}))$ as the edge accuracy value. Similarly, other edge accuracy values for each neighbor relationship are assigned to $E(\mathcal{G_I}))$.

Besides, the pseudocode of *Flexible-Emotion-Edge-Selection* approach is presented in Algorithm 1 in more detail. As described in Algorithm 1, it returns μ as output if we can find a completed *HoF-VEmoBar* from $\mathcal{G_I}$ = $(V(\mathcal{G_I}), E(\mathcal{G_I}))$. Otherwise, it returns $false$.

V. Concluding Remarks and Future Works

In this study, we introduced the *seamless hole-free virtual emotion barrier* which is a barrier system for emotion detection in IoT environment. In the proposed system, the emotion of any person moving from one area to another area can be detected by at lease one IoT device equipped with wireless signal. In particular, the proposed *seamless hole-free virtual emotion barrier* considers to remove *emotion detection hole* with a very low detection accuracy or reduce it in the barrier toward exact emotion derivation. Also, we formally defined the *MaxLoD* problem with ILP formulation and proposed the *Flexible-Emotion-Edge-Selection* scheme. The proposed algorithm includes a creation of initial accuracy graph and returns the minimum accuracy value of the *seamless hole-free virtual emotion barrier* to solve the *MaxLoD* problem.

As future works, we will first implement the proposed scheme through extensive experiments and will evaluate its performance according to practical and various scenarios. Furthermore, because the proposed *seamless hole-free virtual emotion barrier* is built within only square-shaped field, we plan to define *seamless hole-free virtual emotion barrier* with a new view and its possible variations toward various shapes of areas such as circle, convex hull, triangle, etc. Also, it is possible plan for us to expand the detected emotion types and to apply *seamless hole-free virtual emotion barrier* to various applications and systems which require different requirements and objectives.

References

[1] J. Gratch and S. Marsella, "Evaluating a computational model of emotion," *Journal of Autonomous Agents and Multiagent Systems*, pp. 23-43, 2005.

[2] K. Kaulard, D.W. Cunningham, H. H. Bülthoff, C. Wallraven, "The MPI facial expression database — A validated database of emotional and conversational facial expressions," *PLoS ONE*, 2012.

[3] R. Toivonen, M. Kivela, J. Saramaki, M. Viinikainen, M. Vanhatalo and M. Sams, "Networks of emotion concepts," *PLoS ONE*, https://doi.org/10.1371/journal.pone.0028883, 2012.

[4] Z. Kowalczuk and M. Czubenko, "Computational approaches to modeling artificial emotion – an overview of the proposed solutions," *Frontiers in Robotics and AI*, April, 2016.

[5] S. K. Lee, M. Bae, H. Kim, "Future of IoT networks: A survey," *Applied Sciences*, DOI: 10.3390/app7101072, October, 2017.

[6] H. Kim, J. Ko, D. Culler and J. Paek, "Challenging the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL): A Survey," *IEEE Communications Surveys and Tutorials*, pp. 2502-2525, 2017.

[7] H. Ko and S. Pack, "Internet of everything: A large-scale autonomic IoT gateway," *IEEE Transactions on Multi-Scale Computing Systems*, vol.3, pp. 206-214, 2017.

[8] B. Kang, D. Kim and H. Choo, "Internet of everything: A large-scale autonomic IoT gateway," *IEEE Transactions on Multi-Scale Computing Systems*, vol.3, pp. 206-214, 2017.

[9] J. Kim and W. Lee, "Feasibility Study of 60 GHz Millimeter-Wave Technologies for Hyperconnected Fog Computing Applications," *IEEE Internet of Things Journal*, pp. 1165-1173, 2017.

[10] A. Chmiel, J. Sienkiewicz, M. Thelwall, G. Paltoglou, K. Buckley, A. Kappas and J. A. Holyst, "Collective emotions online and their influence on community life," *PLoS ONE*, https://doi.org/10.1371/journal.pone.0022207, 2011.

[11] X. Sun, C. Zhang, G. Li, D. Sun, F. Ren, A. Zomaya and R. Ranjan, "Detecting users' anomalous emotion using social media for business intelligence," *Journal of Computational Science*, https://doi.org/10.1016/j.jocs.2017.05.029, 2017.

[12] M. Chen, P. Zhou and G. Fortino, "Emotion communication system," *IEEE Access*, vol.5, pp. 326-337, 2016.

[13] K. R. Scherer, "Vocal communication of emotion: A review of research paradigms," *Speech Communication*, vol. 40, pp. 227-256, 2003.

[14] M. Suk and B. Prabhakaran, "Real-Time Mobile Facial Expression Recognition System - A Case Study," *Proc. of IEEE Conference on Computer Vision and Pattern Recognition (CVPR) Workshops*, pp. 132-137, 2014.

[15] Z. Zeng, M. Pantic, G. I. Roisman and T. S. Huang, "A survey of affect recognition methods: Audio, visual, and spntaneous expressions," *IEEE Transactions on Machine Intelligence*, vol. 31, pp. 39-58, 2009.

[16] B. C. Ko, "A Brief Review of Facial Emotion Recognition Based on Visual Information," *Sensors*, doi: 10.3390/s18020401, 2018.

[17] D. K. Kim, J. Kim, E. C. Lee, M. Whang and Y. Cho, "Interactive emotional content communications system using portable wireless biofeedback device," *IEEE Transactions on Consumer Electronics*, vol. 57, no. 4, pp. 1929-1936, 2011.

[18] D. S. Quintana, A. J. Guastella, T. Outhred, I. B. Hickie and A. H. Kemp, "Heart rate variability is associated with emotion recognition: direct evidence for a relationship between the autonomic nervous system and social cognition," *International Journal of Psychophysiology*, vol. 86, pp. 168-172, 2012.

[19] F. Agrafioti, D. Hatzinakos and A. K. Anderson, "ECG pattern analysis for emotion detection," *IEEE Transactions on Affective Computing*, vol. 3, no. 1, pp. 102-115, 2012.

[20] Q. Pu, S. Gupta, S. Gollakota and S. Patel, "Whole-home gesture recognition using wireless signals," *Proc. of ACM MobiCom*, 2013.

[21] M. Zhao, F. Adib and D. Katabi, "Emotion recognition using wireless signals," *Proc. of ACM MobiCom*, 2016.

[22] W. Wang, A. X. Liu, M. Shahzad, K. Ling and S. Lu, "Device-free human activity recognition using commercial WiFi devices," *IEEE Journal on Selected Areas in Communications*, vol. 35, pp. 1118-1131, 2017.

[23] M. Raja and S. Sigg, "RFexpress! - RF emotion recognition in the wild," *Proc. of IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, 2017.

[24] D. Gage. "Command control for many-robot systems," in *Proc. of the Nineteenth Annual AUVS Technical Symposium (AUVS-92)*, 1992.

[25] S. Kumar, T.H. Lai and A. Arora, "Barrier coverage with wireless sensors," in *Proc. of the 11th Annual International Conference on Mobile Computing and Networking (MobiCom)*, pp. 284-298, 2005.

[26] S. Kumar, T.H. Lai, M.E. Posner and P. Sinha, "Maximizing the lifetime of a barrier of wireless sensors," *IEEE Transactions on Mobile Computing (TMC)*, vol. 9, no. 8, August, 2010.

[27] L. Li, B. Zhang, X. Shen, J. Zheng, and Z. Yao, "A study on the weak barrier coverage problem in wireless sensor networks," in *Computer Networks*, vol. 55, no. 3, pp. 711–721, 2011.

[28] H. Kim, H. Oh, P. Bellavista and J. Ben-Othman, "Constructing event-driven partial barriers with resilience in wireless mobile sensor networks," *Journal of Network and Computer Applications*, vol. 82, pp. 77-92, 2017.

[29] L. Kong, X. Liu, Z. Li and M. Y. Wu, "Automatic barrier coverage formation with mobile sensor networks," *Proc. of the IEEE International Conference on Communications (ICC)*, pp. 1-5, 2010.

[30] H. Kim, J. Ben-Othman and P. Bellavista, "Collision-free reinforced barriers in UAV networks," *Journal of Computational Science*, vol. 22, pp. 289-300, 2017.

[31] Z. Wang, H. Chen, Q. Cao, H. Qi, Z. Wang and Q. Wang,"Achieving location error tolerant barrier coverage for wireless sensor networks," in *Computer Networks*," vol. 112, pp. 314-328, 2017.

[32] H. Kim, J. Ben-Othman, L. Mokdad, S. Cho and P. Bellavista, "On Collision-free reinforced barriers for multi domain IoT with heterogeneous UAVs," *Proc. of IEEE Annual Ubiquitous Computing, Electronics and Mobile Communication Conference (UEMCON)*, New York, USA, October, 2017.

[33] H. Kim, J. Ben-Othman, S. Cho and L. Mokdad, "On Virtual emotion barrier in Internet of Things," *Proc. of the IEEE International Conference on Communications (ICC)*, Kansas City, USA, May, 2018.

[34] M. Szwoch and P. Pieniazek, "Facial emotion recognition using depth data," *Proc. of the 8th International Conference on Human System Interactions*, Warsar, Poland, pp. 271-277, June, 2015.

[35] W. Wei, Q. Jia and G. Chen, "Real-time facial expression recognition for affective computing based on Kinect," *Proc. of the IEEE 11th Conference on Industrial Electronics and Applications*, Hefei, China, pp. 161-165, June, 2016.