Efficient Localization Scheme based on Coverage Overlapping in Wireless Sensor Networks

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Abstract*—Localization is an important and active topic in wireless sensor networks. This paper proposes a range free localization scheme based on coverage overlapping. The nodes knowing their locations are called reference nodes and the nodes without the knowledge of their locations are called unknown nodes. In addition, for a reference node, the area within its communication range is called the coverage region. In the proposed scheme, an unknown node identifies the coverage regions in which it is located by collecting beacon information from its neighboring reference nodes. The overlapped area of all the coverage regions should be the area where the unknown node is located in. An *overlap point* is defined to represent the overlapped area of two coverage regions. Besides, an *overlap degree*, which is the number of the coverage regions that cover this overlap point, is associated with each overlap point. All the overlap points that are not located in the Estimative Rectangle (ER), which can be derived by applying the CPE algorithm, are discarded. The remaining overlap points are sorted according to their overlap degrees. Moreover, among them, the ones with the maximum overlap degree are averaged and the averaged point is the estimated location of the unknown node. With the proposed mechanism, the reference nodes that cannot contribute to the localization accuracy are excluded, and hence better localization accuracy can be achieved. Experimental results show that the proposed scheme outperforms the related works, including Centroid and CPE algorithms, in term of better localization accuracy.

***Keywords*: wireless sensor networks; localization; coverage overlapping.**

I. Introduction

The rapid progress and integration of wireless communication technology and embedded processor technology have lead to blooming development of Wireless Sensor Networks (WSNs). In a WSN, there can be a large number of sensor nodes each of which has the ability of sensing data and communication. Thus, a WSN can perform real-time data collection, analysis, monitoring and immediate response to events. In order to comply with the demand for the deployment of a large number of sensor nodes, WSNs also have characteristics of low cost, low power, small size, easy to deploy, etc. Because WSNs contain the functions of both wireless communications and sensors, it can be applied to the intelligent office, security surveillance, logistics tracking, home care, staff positioning, home security and other fields [1-5].

Many WSN applications are based on the location information of the sensor nodes. When an event like fire or robbery happens in a WSN environment, in order to deal with the event, one may need to know the location of the sensor node that detects the event. In many circumstances, it is not suitable for all sensor nodes to be equipped with GPS or other additional localization devices. Thus, most of the sensor nodes cannot know their own location information. How to get locations of sensor nodes is one of the most important issues in WSNs and is known as the localization problem.

A lot of different approaches to the localization problem in WSNs have been proposed in the literature [5-11]. In these approaches, there are trade-offs among different factors such as the accuracy of localization, energy saving, hardware cost, the complexity of implementation, etc. The localization approaches can be broadly classified into two categories: range-based schemes and range-free schemes. Range-based schemes use the information of absolute distance or angle between nodes to calculate locations. This information can be obtained by Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength Indicator (RSSI) [5-8]. For example, the Global Positioning System (GPS) is the most well-known location service in the world today. It makes use of Time of Arrival (TOA) technology to compute distance from 24 satellites of six orbital planes so as to estimate the location of the target. Range-based localization schemes require additional hardware to obtain relatively accurate distance (or angle) measurements between nodes. In order to reduce the hardware costs, many range-free localization schemes have been proposed [9-11]. A range-free scheme assumes that no specialized distance or angle determining hardware is necessary for the sensor nodes. That is, in contrast to the range-based schemes, a range-free scheme has the advantages of low computation overhead and less hardware complexity. For example, it is costly for all sensor nodes to be equipped with GPS or other additional localization devices. As low cost is one of the main features of wireless sensor networks, range-free schemes could be more attractive approaches to localization in WSNs.

In this study, we propose a range-free localization scheme: localization scheme based on coverage overlapping (LCO) in a WSN. We assume that a small number of nodes are equipped GPS or other localization devices. They know their locations

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and are called reference nodes. The remaining nodes without the knowledge of their locations are called unknown nodes. In the proposed scheme, reference nodes collect coverage information from the other reference nodes within two hops via two-hop flooding, and then broadcast the collected information to unknown nodes within one hop. An unknown nodes first estimates its location by using the coverage information obtained from its neighboring nodes and then further refine its estimated location by using the coverage information from two-hop reference nodes. Thus, it can derive accurate location estimation.

The rest of this paper is organized as follows: Section II describes the related work in localization for wireless sensor networks. In Section III, the proposed localization scheme based on coverage overlapping is described. The experimental results are presented in Section IV. Finally, conclusion is drawn in Section V.

II. RELATED WORKS

Many localization schemes for WSNs have been proposed in the literature. They broadly fall into two categories: range-based schemes [5-8] and range-free schemes [9-11].

A. Range-Based Localization Schemes

Range-based schemes use the information of measured distance or angle between nodes to compute the locations. This information can be obtained by Time of Arrival (TOA) [5], Time Difference of Arrival (TDOA) [6], Angle of Arrival (AOA) [7], and Received Signal Strength Indicator (RSSI) [8]. Among the range-based localization schemes, the most common technique is Time of Arrival (TOA). TOA uses signal transmission time to estimate the distance between the target and the reference node. Usually this type of system gets the distance information by calculating the signal transmission time. The most common use of Time of Arrival (TOA) technology is Global Position System (GPS). The GPS receiver of a target object uses a number of TOA information of satellite signals to estimate the distance between satellites and the GPS receiver of a target, and then to calculate the target object at the location on the earth.

Time Difference of Arrival (TDOA) is another distance measurement technology. TDOA is similar to TOA. It uses different speeds of two signals to calculate the distance such as radio signals and ultrasound. For TDOA, in addition to the errors which are caused by the time of signal processing, the time interval between two signals is also a source of the estimated error. AOA estimates the distance by measuring angles between neighbors. However, this type of technology often requires some additional expensive and complex hardware.

Received Signal Strength Indication (RSSI) scheme measures the distance based on the attenuation introduced by the propagation of the signal. It measures the power of the signal at the receiver. Based on the known transmit power, the effective propagation loss can be calculated. Theoretical and empirical models can be used to translate this loss into a distance estimate. However, due to problems of multipath fading, unstable signal transmission and background noise, the distance derived from the RSSI may not be accurate.

B. Range-Free Localization Schemes

Unlike range-based localization schemes, range-free localization schemes do not use specific hardware to measure distance or angle between nodes. Pre-configured reference nodes with *a priori* location information are commonly used in range-free localization schemes.

In Centroid algorithm [9], unknown nodes collect location information from their neighboring reference nodes and calculate their estimated locations by using the Centroid formula. The Centroid algorithm is simple and can get accurate estimated location when the anchor ratio is high or the distribution of reference nodes is regular. However, when the reference nodes ratio is low or the distribution of anchors is not even, the estimated location derived from the Centroid algorithm tends to be inaccurate.

Doherty proposed the Convex Position Estimation (CPE) algorithm [10]. When an unknown node hears some reference nodes nearby, it must be within the overlapping region of these reference nodes' communication region. According to the information about the locations and communication range of these reference nodes', the possible location of the unknown node can be calculated. CPE needs a central controller to estimate the location of every unknown node and flood the location to every sensor node. However, the traffic load is heavy and the CPE algorithm scales poorly when the network is large.

Niculescu and Nath proposed a DV-Hop localization scheme [11]. The reference nodes broadcast their location packet throughout the network. Reference nodes exchange coordinate information and the minimum hop count to each reference nodes. Each reference node converts the hop count to physical distance and broadcasts the estimated average distance per hop to the neighboring unknown nodes. Unknown nodes can then calculate their locations based on the received reference node's location, the hop count from the anchor, and the average per hop distance.

III. THE PROPOSED APPROACH

The proposed localization scheme is called localization scheme based on coverage overlapping (LCO). It is assumed that there is a certain number of static sensor nodes randomly deployed in a senor field. Every sensor node has a unique ID. Once a sensor node is deployed, it will not change its location. Besides, there are a small number of nodes that are equipped with GPS or other localization devices. These nodes are called *reference nodes*. The other nodes that have no knowledge about their locations are called *unknown nodes*. If an unknown node can communicate with a certain neighboring reference node, it means that there is a connectivity constraint between the unknown node and this reference node and, more precisely, the unknown node is located within the communication region of this reference node. This implies that the unknown node can compute its estimated location by using the information about the communication ranges of their neighboring reference nodes. The area within the communication range of a reference node is called the *coverage region* of the reference node. Clearly, the unknown node must be located within the overlapped area of all the coverage regions of its neighboring reference nodes. In this study, we devise an efficient localization mechanism based on overlapping the coverage regions of the reference nodes. The details are elaborated as follows.

A. *Coverage Constraints*

Supposing that an unknown node $U(x_u, y_u)$ can receive the beacon messages from n neighboring reference nodes $R_i(x_i, y_i)$ whose communication ranges are all assumed to be r, the following constraints must be satisfied.

$$(x_u - x_i)^2 + (y_u - y_i)^2 \leqq r^2,\ 1 \leqq i \leqq n. \qquad (1)$$

A solution to the above system of inequalities can be considered as an estimation of the location of U. However, it is not easy to solve (1) since the inequalities are nonlinear and hence most of the existing linear programming algorithms can hardly be applied.

From (1), it is easy to see that the unknown node U must be located within the area covered by the circle centered at $R_i(x_i, y_i)$, $1 \leqq i \leqq n$, with radius r. This area is the *coverage region* of the reference node R_i. Clearly, a solution to (1) must be within the overlapped area of the coverage regions of all R_i's. Consider a simple case as shown in Figure 1. The unknown node U must be located both in the coverage regions of reference nodes $R_1(x_1, y_1)$ and $R_2(x_2, y_2)$. That is, any point located in the overlapped area of the coverage regions of R_1 and R_2 is a solution to (1). Moreover, it is easy to reason that the midpoint of R_1 and R_2 is the centroid of the overlapped area. Supposing that the unknown node is uniformly distributed in the sensor field, the centroid point should be a good estimation of the location of U.

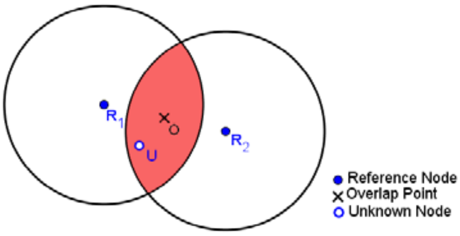

Figure 1. Overlapped coverage regions

According to the above reasoning, for two reference nodes R_1 and R_2 of an unknown node, the midpoint of R_1 and R_2 is defined as the *overlap point* of R_1 and R_2. The overlap point is designated to represent the overlapped area of the coverage regions of reference nodes and can used for location estimation of the unknown node U as elaborated as follows

B. *Location Estimation*

According to the coverage constraints imposed by the reference nodes, a well-known range-free localization scheme was proposed by Bulusu *et al*. [9]. In that scheme, an unknown node collects location information from their neighboring reference nodes and computes its estimated location by using the Centroid formula. The Centroid algorithm is simple and efficient. However, when the distribution of the reference nodes is not even, the estimated location tends to be inaccurate. As shown in Figure 2, the shadow region is the overlapped area of the coverage regions of three reference nodes R_1, R_2 and R_3. Clearly, the unknown node should be located in the shadow region. However, by using the Centroid algorithm, the estimated location, denoted as C, of the unknown node is the average of the coordinates of R_1, R_2 and R_3, which is outside the shadow region.

To improve the location accuracy, the overlap point described above is useful since it can be used to represent the overlapped area of two communication regions. In Figure 2, the overlap points of R_1 and R_2, R_2 and R_3, R_1 and R_3 are denoted as O_{12}, O_{23} and O_{13}, respectively. We can see that O_{12} and O_{13} are within the shadow region and hence can be useful for location estimation, whereas O_{23} does not seem to be helpful for accurate location estimation since it is far away from the shadow area. This observation reveals that if the overlap points that are far away from the shadow area are excluded, the remaining overlap points can be used to derive accurate location estimation.

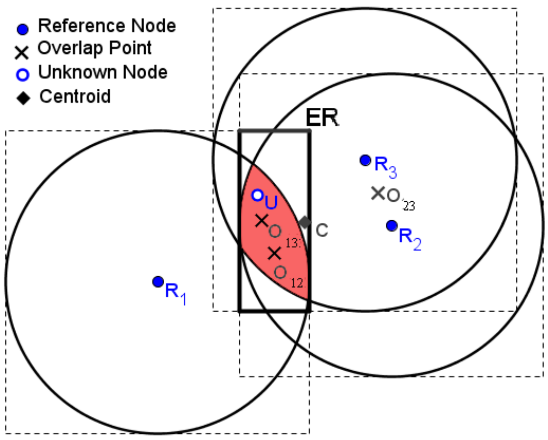

Figure 2. Filtering overlap points by ER

We call an overlap point *improper* if it is far away from the shadow region. For the purpose of identifying the improper overlap points, the CPE scheme proposed by Doherty *et al*. [10] is adopted. The CPE algorithm defines the Estimative Rectangle (ER) to bound the overlapped region. For ease of computation, the derivation of ER is a little modified as presented in [11]. A square of size $2r$ is used to bound the coverage region of a reference node, whose communication range is r. Thus, the ER of the unknown node is the overlapped area of all the squares that bound the coverage regions of the reference nodes. As shown in Figure 2, there are three square regions each of which is for a reference node. The overlapped area of these three square regions (the bold-line box) is the ER, inside which the unknown node must be located. By adopting the CPE scheme, we devise a filtering mechanism to filter out the improper overlap points, which are much unlikely to be helpful for accurate location estimation. The mechanism can be described as follows: At first, all the overlap points of every two reference nodes are computed. Also, the Estimative

Rectangle (ER) that bounds the overlapped region is derived with the CPE algorithm. Then, each overlap point is checked to see if it is located in the ER. If it is located outside the ER, it is considered as improper and is discarded. Finally, the remaining overlap points are averaged, and the averaged point is the estimated location of the unknown node.

As shown in Figure 2, the overlap points O_{12} and O_{13} are inside the ER and the overlap point O_{23} is outside the ER. Thus, O_{23} is improper and is excluded. The average of O_{12} and O_{13}, which must be inside the ER (since O_{12} and O_{13} are inside the ER), should be a good location estimation for the unknown node.

According to the definition of overlap point, an overlap point of reference nodes R_1 and R_2, denoted as O_{12}, is of course located in both the coverage regions of R_1 and R_2. However, one may find that it is possible that O_{12} is also located in the coverage region of a reference node other than R_1 and R_2. For example, as shown in Figure 3, O_{13} is the overlap point of R_1 and R_3. We can see that O_{13} is not only located within the coverage regions of R_1 and R_3 but also within the coverage region of R_2. In light of this observation, we associate the overlap point with an *overlap degree d*. The value of *d* is the number of the coverage regions that include this overlap point. For example, in Figure 3, the overlap degree of O_{13} is 3 since it resides in the coverage regions of R_1, R_2, and R_3. Thus, the overlap points with high overlap degree can be taken to derive accurate location estimation. This can be easily achieved by sorting the overlap points according to their overlap degrees.

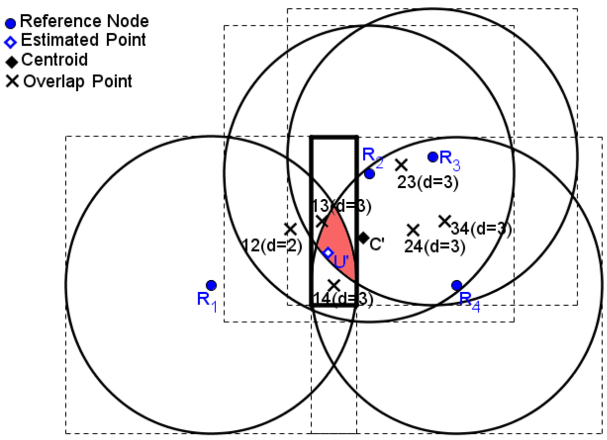

Figure 3. Selecting overlap points by overlap degrees

From the above discussion, the proposed localization scheme can be described as the following steps.

1. The unknown node derives the coverage regions in which it is located by collecting beacon information from its neighboring reference nodes.
2. All the overlap points of every two coverage regions are derived. Meanwhile, the overlap degree for each overlap point is also computed.
3. Every overlap point is checked to see if it is located in the Estimative Rectangle (ER), which is derived by applying the CPE algorithm as described above.
4. For all the overlap points that are located in the ER, they are sorted according to their overlap degrees. (In some special cases that there is no any overlap point inside the ER, all the overlap points are sorted.)
5. The overlap points with the maximum overlap degree are averaged. The averaged point is the estimated location of the unknown node.

Consider the example shown in Figure 3 again. There are four reference node and six overlap points (the *d* value is the overlap degree). Two overlap points O_{13} and O_{14} are located in the ER and both of their overlap degree are 3. Hence, the averaged point (*U'*) of O_{13} and O_{14} is the estimated location of the unknown node. We can see that *U'* is of course located in the ER and is also located in the overlap area in this example. Hence, it is a good location estimation in the sense that the unknown node must be also located in the overlap area. In contrast, the *C* point derived by CPE algorithm is located outside the overlap area and is relatively not a good estimation.

IV. SIMULATION AND PERFORMANCE EVALUATION

Simulation is performed with C codes to compare the performance of the proposed algorithm LCO with other range-free localization schemes, including Centroid and CPE.

A. *Simulation Environments*

In our simulation, it is assumed that all the sensor nodes have the same communication range of 30m. Also, all the unknown nodes and reference nodes are randomly distributed in a 300m*300m square region, and each node has a unique ID. Once a sensor node is deployed, it will not change its location. In the simulation, two parameters are varied: the density of reference nodes and the communication range of sensor nodes. The density of reference nodes is $m/(n+m)$, where n is the number of unknown nodes, and m is the number of reference nodes in the WSN. The location error is defined as the distance between the position determined by the algorithm and the true location of the unknown node, and the mean location error is the average location error of all unknown nodes.

B. *Effects of Reference Node Density*

In the simulation, the total number of sensor nodes is 200. The number of reference nodes is varied from 10 to 100. Figure 4 shows the impact of the reference node density on the mean location error. As the density of reference nodes increases, the mean location error decreases for all the three approaches, i.e., LCO, Centroid and CPE. Centroid and CPE take all the information of reference nodes to obtain the estimated location and their mean location errors are almost the same. In contrast, in LCO scheme, the reference nodes that constitute improper overlap points are not taken into account. That is, only the reference nodes that will contribute to better localization accuracy are used in the proposed mechanism. Therefore, the proposed scheme LCO has better localization accuracy than Centroid and CPE schemes.

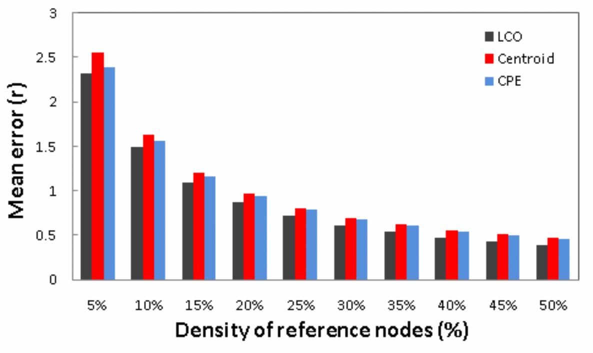

Figure 4. Effects of reference node density

C. *Effects of Communication Range*

In the simulation, the total number of sensor nodes is 200. The density of reference nodes is 30%. The communication range of sensor nodes varies from 10m to 50m. Figure 5 shows the effects of the communication range on the mean location error. We can see that as the communication range of sensor nodes increases, the mean location error decreases for all the three approaches. This is because that more information of reference nodes can be obtained by the unknown nodes as the communication range increase. Again, Centroid and CPE take all the information of reference nodes to obtain the estimated location and their mean location errors are almost the same. In contrast, our proposed scheme always has better localization accuracy than Centroid and CPE schemes since the reference nodes that constitute improper overlap points are not taken into account while performing the location computation.

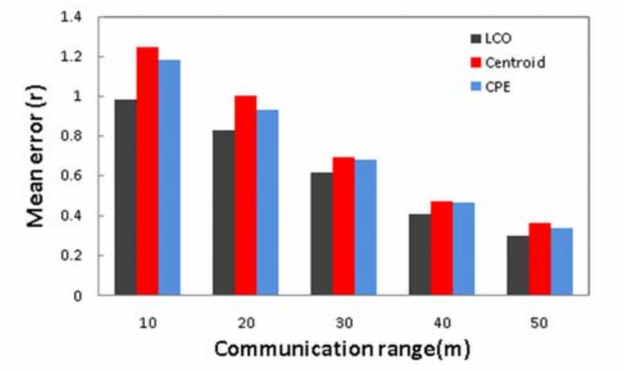

Figure 5. Effects of communication ranges

V. CONCLUSIONS

Localization is a fundamental and essential research issue in WSNs. In order to reduce the cost of communication and computation and to enhance the accuracy of location estimation, we propose a range-free localization scheme based on coverage overlapping, named LCO for short. In the proposed scheme, the unknown node identifies the coverage regions of its neighboring reference nodes. An overlap point is defined to represent the overlapped area of two coverage regions. We devise a filtering mechanism to filter out the improper overlap points that are very unlikely to be helpful for deriving accurate location estimation by checking if they are located in the Estimative Rectangle (ER), which can be derived by applying the CPE algorithm. Besides, an *overlap degree*, which is the number of the coverage regions that cover the overlap point, is associated with each overlap point. All the overlap points that are located in the ER are sorted according to their overlap degrees, and the ones with the maximum overlap degree are averaged. The averaged point is the estimated location of the unknown node. The proposed mechanism has the merits of low communication and computation cost because it is easy to identify the coverage regions of reference nodes and to derive the overlap points together with their respective overlap degrees. Moreover, in comparison with Centroid and CPE schemes, simulation results show that the proposed scheme always has better localization accuracy since the reference nodes that cannot contribute to the localization accuracy are excluded while performing the location estimation, and only the overlap points with the maximum overlap degree are utilized for location computation.

REFERENCES

[1] I. F. Akyildiz, W.Su, Y. Sankarasubramaniam, and E. Cayirci, "A Survey on Sensor Networks," IEEE Communications Magazine, vol. 40, pp. 102-114, August 2002.

[2] D. Estrin, L. Girod, G. Pottie, and M. Strivastava, "Instrumenting the World with Wireless Sensor Networks", International Conference of Acoustics, Speech, and Signal Processing (ICASSP), vol. 4, pp. 2033-2036, May 2001.

[3] D. Estrin, R. Govindan, J. Heidemann, and S. Kumar, "Next Century Challenges: Scalable Coordination in Sensor Networks," 5th Annual International Conference on Mobile Computing and Networking (MOBICOM), pp. 263-270, Washington, USA, August 1999.

[4] G.J. Pottie, and W.J. Kaiser, "Wireless Integrate Network Sensors", Communications of the ACM, vol. 43, no. 5, pp. 551-558, May 2002.

[5] K. Lorincz and M. Welsh, "MoteTrack: a robust, decentralized approach to RF-based location tracking," Personal and Ubiquitous Computing, vol. 11, no. 6, pp. 489-503, 2007.

[6] A. Catovic and Z. Sahinoglu, "The Cram´er-Rao bounds of hybrid TOA/RSS and TDOA/RSS location estimation schemes," IEEE Communications Letters, vol. 8, no. 10, pp. 626-628, 2004.

[7] D. Niculescu and B. Nath, "Ad Hoc Positioning System (APS) using AOA," 22nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2003), pp. 1734-1743, vol. 22, March 2003.

[8] P. Bahl, and V. N. Padmanabhan, "RADAR: An In-Building RF-based User Location and Tracking System," 19th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2000), vol. 2, pp. 775-784, Tel Aviv, Israel, March 2000..

[9] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less Low Cost Outdoor Localization for Very Small Devices," IEEE Personal Communication Magazine, vol. 7 no. 5, pp. 28-34, October 2000.

[10] L. Doherty, K.S.J. Pister, and L.E. Ghaoui, "Convex Position Estimation in Wireless Sensor Networks," 20nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2001), vol. 3, pp. 1655-1663, April 2001.

[11] J. P. Sheu, P. C. Chen, C. S. Hsu, "A Distributed Localization Scheme for Wireless Sensor Networks with Improved Grid-Scan and Vector-based Refinement," IEEE Transactions on Mobile Computing, Vol. 7, No. 9, pp. 1110-1123, September 2008.