

A Context-Aware Routing Protocol on Internet of Things Based on Sea Computing Model

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Abstract— The paper syncretizes the fundamental concept of the Sea Computing model in Internet of Things and the routing protocol of the wireless sensor network, and proposes a new routing protocol CASCR (Context-Awareness in Sea Computing Routing Protocol) for Internet of Things, based on context-awareness which belongs to the key technologies of Internet of Things. Furthermore, the paper describes the details on the protocol in the work flow, data structure and quantitative algorithm and so on. Finally, the simulation is given to analyze the work performance of the protocol CASCR. Theoretical analysis and experiment verify that CASCR has higher energy efficient and longer lifetime than the congeneric protocols. The paper enriches the theoretical foundation and makes some contribution for wireless sensor network transiting to Internet of Things in this research phase.

Index Terms— context-awareness, Internet of Things, routing protocol, energy efficient, Sea Computing

I. INTRODUCTION

Recent rapid progress in sensor, networking, and RFID (Radio Frequency Identification Devices) technologies allows connecting various physical world objects to the cyber infrastructure, which could enable realization of the Internet of Things (IOT) vision. IOT is a technological revolution that represents the future of computing and communications, and it aims at increasing the ubiquity of the Internet by integrating every object for interaction via embedded systems, which leads to the highly distributed network of devices communicating with human beings as well as other devices[2]. Sea Computing is a new model of IOT, which emphasizes the intelligence of the nodes. Interaction between nodes has been significantly enhanced, and the nodes deal with the gathering information themselves rather than transmit it to the others [3].

The technologies of wireless sensor network (WSN) are the concrete representations for implementing the IOT vision, and the specialties low-dissipation, low-cost, distributed and self-organized bring an important revolution in the computer application domain [4]. The essential characteristic of the IOT is transparency. The context-aware computing will debase the degree of the humankind participating straight greatly then implementing transparency intercommunion through apperceiving the useful information to reason, decide and calculate automatically. Therefore, the research on the context-aware computing is very important to implement

the imagination of the IOT. Its appearance and development correspond to the need of individual and multi-kind in the future with high informationization[5-6]. This paper chooses the context-awareness to be the research keystone as the junction of the IOT thought and WSN technology. The protocol CASCR (Context-Awareness in Sea Computing Routing Protocol) is brought forward in this paper on aiming at the existent problems in the existing WSN routing protocol. Some promoting effect reference value and scientific basis to some extent will be brought in the domain of the IOT.

The rest of the paper is organized as follows. In Section II, we discuss the related work. In Section III and IV, we present the key technologies, context-awareness and sea computing, of the paper. Section V describes our proposed routing protocol for IOT with formal definitions. We evaluate our protocols in Section VI, and conclude in Section VII.

II. RELATED WORK

The academia sorts the IOT/WSN routing protocols some kinds according to different standards [7-8]. It can be sorted into two kinds below by the communication ways of the nodes: complanate routing protocols and hierarchical ones. Concretely, the hierarchical ones need the support of the basal general routing protocol working in the clusters. They also can be sorted into the ones based on the data and the ones based on the location information by the discovering procedure of the routing.

The IOT/WSN routing protocols are not mature enough, and lots of them are in the academic research phase. Some analysis to the classical ones will be given as below [9-10].

(1) The protocol LEACH (Low Energy Adaptive Clustering Hierarchy) ignores the concrete energy problem that the cluster head nodes assemble together easily in the election so as to the illusive randomness. The formula considers the randomness and misses the logicity.

(2) Although SPIN (Sensor Protocols for Information via Negotiation) solves the resource wasting like information blast and information redundancy through the negotiating mechanism with the localized topology as the CASCR in this paper, the complicated “three times shake-hands” and the inflexible energy threshold all make SPIN poor in the energy efficient.

(3) As the representation of the routing protocol based on the query, the manner Rumor on the random single-cast lack the guarantee in reliability and logicity. Rumor cannot get rid of the unoptimizable problem and the routing ring in the path producing.

(4) The routing algorithm EPGR (Energy Prediction and Geographical Routing) given in the reference [11] cannot reflect most WSN nodes' different working states practically with the node's states designed in it. And its designing is complicated and poorly representational; The algorithm DMMDR (Dynamic Multifactor Markov Decision Routing) given in the reference [12] designs the sensor nodes into different states, but the topology variety's uncertain and frequency in the practical deployment of WSN will make the scale of the "states" here instable and uncertain. The DMMDR discusses the WSN topology problem with the topological structure only and is lack of the application rationality; the model CTMPC (Context-based Triggered Task Model in Pervasive Computing) given in the reference [13] is an application representation of the context-aware computing. But this model and other similar research thoughts given by the academia are only settling in the theoretical reasoning level and the qualitative plan level. They are unable to deploy quantitatively and standardly in the concrete application as the superficial research level of the context-aware computing. The application of the context-awareness in the pervasive computing environment in the future must merge with mathematics tool so that the integrated indices of the WSN routing technology can be improved better; the algorithm MAFZP (Mobility Aware Fast Zoned Protocol) given in the reference [5] does not make full use of the context-aware computing with the far-fetched designing model. It cannot reflect the context relationship of the nodes' movement well and be lack of the technical interfusion in the details. So it cannot be considered as a representative designing of the context-awareness core thought merging with the concrete application deeply for the lower specialty exertion of the context-aware computing.

III. CONTEXT-AWARE COMPUTING

What is called context-awareness is a kind of controlling, obtaining and analyzing technology to the context information. And the mutative information of this ambient environment is so-called "context", for example, the geography location, environment information, jitter data or states of the monitored target.

The context-aware computing includes five sub-technologies mainly: (1) context-getting (2) context-modeling (3) context-reasoning (4) context-conflict-solving (5) context-storage and management.

A context-aware system means that a system which can use the context information and do some corresponding change or configuration automatically as the variety of the context information to provide the users individual proper context service [13]. The protocol

CASCR given in this paper makes the IOT a context-aware system.

The context-awareness has an extensive application field in human production living like the intelligent official work, house-hold service, medical treatment and so on. For implementing the application system intelligent, controllable and predictable highly as the final destination of the context-aware computing, making the topology states in the IOT system predictable and reasonable to some extent through utilizing the IOT nodes' relevant real-time information, data, states and parameters as the context knowledge is positive to the IOT routing technology in the present development phase [14-15].

IV. SEA COMPUTING MODEL

Sea Computing is a new computing model of IOT. Through embodying the computing unit and communications equipment in the physical world objects, the objects can interconnect with each other. Even in the scene which is unpredictable in advance to judge, Sea Computing can realize the interaction between nodes. Its essence is making the information device invisibly integrate into the real physical world everywhere, and extending the informatization to the physical world.

On the one hand, by strengthening the variety embodying information devices in the objects, making objects and information devices achieve a close integration, the objects could natively obtain the information about the physical world; on the other hand, by strengthening the local real-time interaction and distributed intelligence between mass individual things, the objects will be provided with self-organization, self-calculation and self-feedback of Sea Computing functions. The goal of Sea Computing is the intelligent communication between objects, realizing the interaction of things, emphasizing the intelligent connection and physical properties emergence in the physical world. It is a physical world-centric perspective.

The characteristic of Sea Computing is [3]:

- (1) **Embodiment.** Information devices are embodied into various things, so do the sensors. The information devices have the same lifecycle as the object, and it is self-management and self-maintenance.
- (2) **Autonomy.** The objects are not controlled passively, but possess a certain autonomous and autonomic ability.
- (3) **Local Interaction.** Sea Computing make full use of locality principle, and things are mainly through local interaction to realize communication.
- (4) **Swarm Intelligence.** Sea Computing model of IOT is a dynamic self-organizing system. The intelligent algorithm in one node can't know the result in advance, and it needs to interact with the other ones through the embedded intelligent algorithm to produce the effective intelligent decision.

Due to the characteristic described above, in Sea Computing model the routing protocol not only transmits the data, but also perceives the data. The routing is established to transfer the data, and meanwhile, the data promotes the routing. CASCR based on Sea Computing uses context-aware computing to perceive the information and to optimize the routing.

V. THE PROTOCOL CASCR

With syncretizing the context-aware computing, the protocol CASCR (Context-Awareness in Sea Computing Routing Protocol) considers the inherent specialties of the IOT adequately and utilizes multi-kinds context information to describe and review the work state data of the nodes roundly. It can control the nodes' variety trend in the long time running effectively and elevate the using efficiency of the energy.

A. Formal Definitions and Basal Work flow & Thought

In this section we will define some fundamental thoughts of CASCR protocol, and the detail information will discuss in the next section.

For the brevity of discussion, we use the following notation for formal definitions and quantitative.

$N(A)$	node with identifier A
$Nei(A)$	neighbor nodes of $N(A)$
$Sup(A)$	superior nodes of $N(A)$
$Sub(A)$	subordinate nodes of $N(A)$
$Col(A)$	colleague nodes of $N(A)$
$S(A)_{f-w}$	one of the five states for $N(A)$ represents that $N(A)$ is in the state of full-working, and from this state, $N(A)$ can change into the other states under some specific condition
$S(A)_{ser}$	the second state which means $N(A)$ is in the state of serving
$S(A)_{s-w}$	the third state, which means $N(A)$ is in the state of single-working
$S(A)_{sle}$	the forth state, which means $N(A)$ is in the state of sleeping
$S(A)_{hib}$	the fifth state, which represents that $N(A)$ is in the state of hibernating
$slice(n)$	the n^{th} time unit
$Rate(M)_{Energy-Consumption}$	dynamic context information of $N(M)$, which represents the rate of energy consumption in the past timeslices
$Instant(M)_{Consumption-Rate}$	dynamic context represents the instant value of consumption of $N(M)$
$Life(M)_{Residual-Energy}$	dynamic context represents the

$lifetime$	lifetime of residual energy of $N(M)$
$Queue(M)_{Pending-Tasks}$	dynamic context which stands for the pending task queue of $N(M)$ in the future timeslices
$CF(E_i)$	trust degree for the state transforming probability
$Dis(A,B)$	the number of hops between $N(A)$ and $N(B)$
$N(A) \triangleleft M(X)$	$N(A)$ receives message M from $N(X)$
$WT(A)$	the working time of $N(A)$
H_j	transforming the current state to state j
EC	short for $Rate(M)_{Energy-Consumption}$
CR	short for $Instant(M)_{Consumption-Rate}$
RE	short for $Life(M)_{Residual-Energy}$
PT	short for $Queue(M)_{Pending-Tasks}$
$Tran(A)$	the transferring process of $N(A)$, working with H_j to specify the node's ID
$CF_{H_j}(E)$	the trust degree for state transforming to state j
$P_{H_j}(E/S)$	the posterior probability of trust degree for transforming to state j, being equivalent to $CF_{H_j}(E)$
$P(H_j/S)$	the posterior probability of H_j , equivalent to $P_{H_j}(E/S)$

The complanate routing protocol is more efficient than the hierarchical ones in the middle or small scale IOT network and inside the clusters. It has the low complexity, implementation cost, good controllability, transplantation and extensive application range characteristic. So the CASCR given in this paper designed as a complanate routing protocol can be transplanted into the clusters of the hierarchical routing protocol.

Each node has a relative notation set with the other nodes, which are $Nei(A)$, $Sup(A)$, $Sub(A)$ and $Col(A)$. For the further discussion briefly we define them first.

Definition 1: (1) The neighbor nodes of $N(A)$, $Nei(A)$, is a set of nodes which can reach node A with only one hop, i.e., $Nei(A) := \{N(x) | x : Dis(N(x), N(A)) = 1\}$.

(2) The superior nodes of $N(A)$, $Sup(A)$, is a set of neighbor nodes which send the gathering message to $N(A)$, i.e., $Sup(A) := \{N(x) | x : N(x) \in Nei(A), N(A) \triangleleft M(x)\}$.

(3) The subordinate nodes of $N(A)$, $Sub(A)$, is a set of neighbor nodes which receive the message from node A, i.e., $Sub(A) := \{N(x) | x : N(x) \in Nei(A), N(x) \triangleleft M(A)\}$.

(4) The colleague nodes of $N(A)$, $Col(A)$, is a set of neighbor nodes which neither are the $Sup(A)$ nor the $Sub(A)$, i.e., $Col(A) := \{N(x) | x : N(x) \in Nei(A), N(x) \notin Sup(A), N(x) \notin Sub(A)\}$

Figure 1 illustrates one example of the relationships of the nodes. The nodes $N(0)$, $N(5)$, $N(3)$, $N(1)$, $N(2)$ and $N(7)$ are all the neighbor nodes of $N(6)$. Therein, the $N(0)$, $N(5)$ and $N(3)$ are the superior nodes of the $N(6)$; As the same, $N(7)$ is the subordinate node; $N(1)$ and $N(2)$ are the colleague nodes of $N(6)$. But $N(4)$ is not like any one of them.

The subordinate and superior nodes can exchange in Sea Computing model, because in IOT a node can transmit the gathering data to the subordinate nodes, and also can send the controlling message to the superior nodes. But in this paper, we make a unified definition to prevent misleading.

There are some different work schemes in the sensor nodes to suit the different work environment and the mutative portfolio flow with time. Every work scheme predefined is called a work state. The nodes adopt different work manners and energy scheme to achieve the goal that adapt the environment and save energy through changing their work states. There are five different states defined in the protocol CASCR.

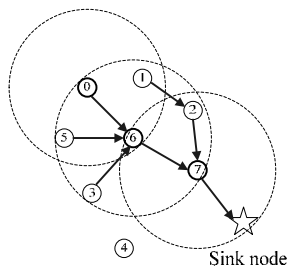


Figure 1. The relationships of the neighbor, superior, subordinate and colleague nodes

Definition 2: Operations and States

Operations:

Operation 1, gathering: The node’s sensor assembles the information from the surrounding environment.

Operation 2, transmitting: The node’s transceiver transfers the data and controlling operations for its superior and subordinate nodes.

Operation 3, fusing: The node’s intelligent information device deal with the gathering data by compressing and fusing before transmitting them to other nodes.

Operation 4, controlling: The node receives the operation order, and the intelligent algorithm of information device control the object.

Operation 5, Sleeping: Through the intelligent algorithm of information device, the node could turn into sleeping. If the node is sleeping, it will not transmit the data, and the processor runs in very low power. But if the node needs to come back for work, the transceiver and processor will launch quickly.

Operation 6, Hibernating: The node shuts itself down, and it would not gather data, transmit information or fuse it. But the timer is still working, so that the node still synchronizes with the others.

States:

State 1: $S(A)_{f-w}$, which means that every module in the node A is in the working state. The node needs to do the former four operations above including gathering, fusing, and sending the controlling data that needs to be done by itself and at the same time transmits the data information of its superior nodes.

State 2: $S(A)_{ser}$, which means the node accomplishes its work and transmits the data and controlling operations for its superior.

State 3: $S(A)_{s-w}$, which means the node just gathers the environment information and fuses it by itself but not any other nodes.

State 4: $S(A)_{ste}$, which means that the transmitter will be shut down and the processor will be down to the lowest. The receiver will be set to work on the low power waste state.

State 5: $S(A)_{hib}$, which means that the transmitter, receiver and processor will be all shut down except the timer. The node stays in the absolute still state.

Definition 3: The long time running nodes in the WSN will work as the timeslice that are equal in length. So the transition of the states in the Definition 2 is according to the timeslice as basal units. The sensor nodes must work in a kind of states n slice time. Thereinto, n is integer.

$N(A)$ ’s working time can include one or more timeslice. $WT(A) := \{\{slice(t)\} | t \in \mathbb{N}^k\}$, \mathbb{N} is infinite integer domain.

Definition 4: The dynamic context of the nodes is the most straight and effective context information that can be researched quantitatively. The dynamic context of the nodes are the information in all kinds that can be used to describe the dynamic work status of the nodes in the IOT application environment including the energy consuming rate, processing task quantity per fixed time, and the work states’ variety information of the nodes and so on.

The context data message for election to the next hop just transmit among the nodes that have straight operation contact i.e. the operation superior just calculating and forecasting the future work state for its operation subordinate and then the useful context information in single hop area will be in control in the IOT which running the CASCR. The whole IOT network has initialized steady effective routing before the CASCR’s running. Based on this precondition, we consider that

there are not redundant route, roundabout route and short-inefficient ones in any local topology of the IOT. And some trivial simple questions will not be given definitely for simplifying the length of this paper.

B. Detail Definition and Data Structure

There are five states: full-working, serving, single-working, sleeping, hibernating states defined in the CASCR as the program in the section above, definition 2. Before discussing the details, we first introduce one rule for the nodes' working states transferring.

Rule: The node cannot transfer to the state 4 or state 5 from the state 4 or state 5, i.e.,
 $Tran(A) := \{H_j | j : S(A)_{sle} \rightarrow \neg H_4, S(A)_{sle} \rightarrow \neg H_5, S(A)_{hib} \rightarrow \neg H_4, S(A)_{hib} \rightarrow \neg H_5, j \in [1,5]\}$

The state 4 and 5 can only be the transition results of the other three states. This design will decrease the probability of false disability of the vast nodes in the IOT.

The protocol CASCR combines with the AI (artificial intelligence) theory and Markov probability tool quantitatively process the data in kinds gathered by the nodes at every time slice according to a set of adjustable states transition rules and then input the quantitative module of the CASCR for the effective parameters that can be used to forecast the states variety trend at last. Like the figure 2 below.

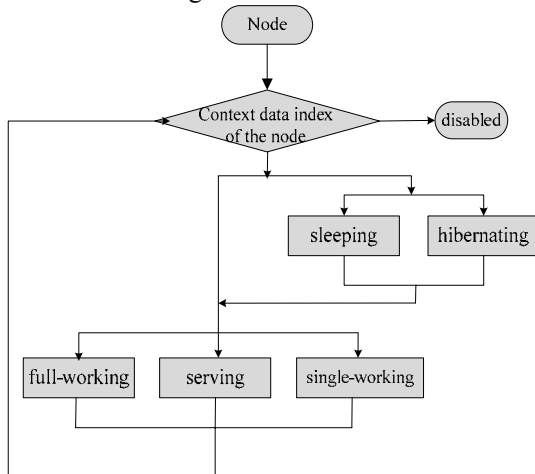


Figure 2. The demonstration of the transitions between the states of the nodes

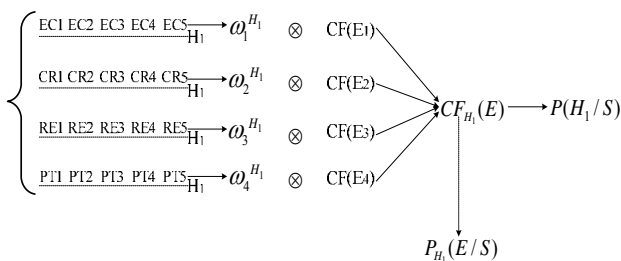


Figure 3. The processing thought on the main data of the CASCR

Through utilizing the 5×4 data as sets (illustrating by figure 4) to compute with the adjustable states transition conclusion $H_1 \sim H_5$ stored in the nodes, the weight $\omega_i^{H_j}$ relative to every conclusion will be obtained and then the weights will combine with trust degree $CF(E_i)$ of that kind of the data, i.e. the trust degree of the evidence in this observation. After that, the integrated accordant degree $CF_{H_i}(E)$, i.e., $P_{H_i}(E/S)$, relative to conclusion H_j for the node in this timeslice will be obtained. It is considered as posterior probability $P(H_1/S)$ of the integrated evidence in the dynamic observation. At last, the state transition matrix stored in the node will be initialized through computing to get other four posterior probability values to the other four states. These values are all based on the context data in a timeslice's first half. In this paper, a time slice unit is set as 10 minutes to be an example (the concrete value can be adjusted in the different scenes or simulation environment). So the first 5 minutes in the timeslice will represent the node's working state in the second 5 minutes and even the future.

	$\omega_1^{H_j}$	$\omega_2^{H_j}$	$\omega_3^{H_j}$	$\omega_4^{H_j}$
H_1	$\omega_1^{H_1}$	$\omega_2^{H_1}$	$\omega_3^{H_1}$	$\omega_4^{H_1}$
H_2	$\omega_1^{H_2}$	...	...	...
H_3	...	...	...	...
H_4	...	...	...	...
H_5	$\omega_1^{H_5}$	...	...	$\omega_4^{H_5}$

Figure 4. The mapping for $\omega_i^{H_j}$ stored in node

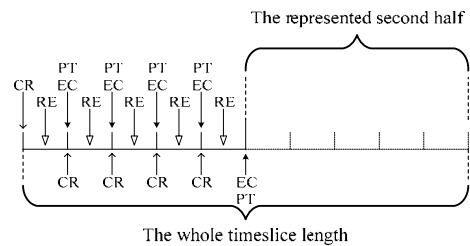


Figure 5. Collect the context data in a time slice

Definition 5: Rate of the node's energy consumption in the i_{th} timeslice, $Rate^i_{Energy-Consumption} = \frac{e_{i+1} - e_i}{1} (J/min)$, there into e_i is the residual energy value of the battery in node as the unit Joule, and the positive integer i is in the field [0,4].

Gather five residual energy values of the battery a, b, c, d, e as the unit Joule and use the latter value minus the former to get the real energy consumption in the past 1 minute. For the six values: $e_1 = a$, $e_2 = b$, $e_3 = c$, $e_4 = d$,

$e_s = e$ and one initial value $e_0 = ini$, there are five $Rate^i_{Energy-Consumption} = \frac{e_{i+1} - e_i}{1}$ values. These five parameters will be used as $Rate(M)_{Energy-Consumption}$ data.

Definition 6: Instantaneous value of consumption, $Instant(M)_{Consumption-Rate}$, is obtained through gathering instantaneous energy consumption rate value on the five times instant and use them as $Instant(M)_{Consumption-Rate}$ directly with the unit J/min .

Definition 7: Queue of pending tasks data, $Queue(M)_{Pending-Tasks}$, is obtaining in the same way as the CR data. Gather five residual data queue length values of the node and use them as the $Queue(M)_{Pending-Tasks}$ directly. The measurement of the queue length is according to the concrete IOT environment with the fixed length data as the standard value 100%.

Definition 8: Lifetime of residual energy,

$Life^i_{Residual-Energy} = \frac{e_{i+1} - e_i}{CR^{i+1} - CR^i} \cdot \frac{e_s}{CR^5}$, therinto e_i is the residual energy value of the battery in node as the unit Joule, and the positive integer i is in the field [1,4]; CR^i presents instantaneous energy consumption rate $Instant^i_{Consumption-Rate}$.

The RE data is for gathering five residual time data of the battery. Divide the present residual energy value e_i by the present instantaneous energy consumption rate value z_i and five instantaneous residual time value of

the battery $t_i = \frac{e_i}{z_i}$ will be obtained with the positive integer i in the field [1,5]. We use the latter value minus the former to get the residual time rate of change of the battery relative to the one minute past for reflecting the degree of change and consumption rate of the battery energy residual time in this first half time slice. It can be positive or negative. Four v_i values will be got through $v_i = t_{i+1} - t_i$ with the positive integer $i \in [1,4]$. At last, we divide v_i by the last value t_5 to get four $LifeTime_{Residual-Energy}$ data, i.e.

$LifeTime^i_{Residual Energy} = \frac{v_i}{t_5}$. Several types of the four data in the matching with the transition rules (refer to the Table 1); the semantic distance method will not be

adopted for the unidirectivity of the data bound in the items. It is judged just by how many data accord with the standard values in the four. It will be set to 1 if all do with also can be set to $\frac{3}{4} \times 1$ if there are three do. The other items will be calculated by the ways of semantic distance.

The protocol CASCR chooses the next hop succedaneous node in the single hop area. The superior nodes send a routing election request message in their neighbor area and the destinations will be confirmed as the environment context data table stored in the nodes (illustrating by Figure 6 and 7). The destination nodes that receive the request message will reply a routing election reply message according to their context data situation (illustrating by Figure 8). CASCR don't adopt the manner of periodic synchronization to decrease the cost of communication and quantity of the packets among the nodes.

Routing Election Request Message			
1	2	3	4
Dest	Src	Next hop	Second hop

Figure 6. The format of the Routing Election Request message

Environment Context Data Table			
Present neighbor node	...	...	...
Present subordinate node	...	...	...
Present superior node	...	...	...
Present colleague node	...	...	...
temporary disabled node	...	...	...

Figure 7. The structure of the Environment Context Data Table

The third and fourth item in the Figure 8 are used to judge whether the reply nodes are the neighbour of the nodes will be replaced and its next hop one.

Several data structures stored in the nodes are the context data table (CDT) to store the context data information of this node, the subordinate context data table (SCDT) to store context data information of the subordinate nodes of this node, the environment context data table (ECDT) to store context data information of the ambient nodes of this node in a single hop neighbour area. The traditional routing table has the problems of items scale, time to live, onefold function and out of date and so on [16]. The CDT implements the functions of the traditional routing table in the conventional routing protocol uniformly and exceeds the category of the onefold routing information.

Routing Election Reply Message																												
1		2		3		4		5					6					7					8					9
Dest	Src	Boolean1		Boolean2		Rate _{Energy-Consumption}					Instant _{Consumption-Rate}					LifeTime _{Residual-Energy}					Queue _{Pending-Tasks}					CurrentState		
ID1	ID2	Y/N	Y/N	EC1	EC2	EC3	EC4	EC5	CF(E1)	CR1	CR2	CR3	CR4	CR5	CF(E2)	RE1	RE2	RE3	RE4	RE5	CF(E3)	PT1	PT2	PT3	PT4	PT5	CF(E4)	1/2/3/4/5

Figure 8. The format of the Routing Election Reply message

Context Data Table																								
Rate _{Energy-Consumption}						Instant _{Consumption-Rate}						LifeTime _{Residual-Energy}						Queue _{Pending-Tasks}					CurrentState	
EC1	EC2	EC3	EC4	EC5	CF(E1)	CR1	CR2	CR3	CR4	CR5	CF(E2)	RE1	RE2	RE3	RE4	RE5	CF(E3)	PT1	PT2	PT3	PT4	PT5	CF(E4)	1/2/3/4/5

Figure 9. The structure of the Context Data Table in this node

Subordinate Context Data Table					
Node ID	Rate _{Energy-Consumption}	Instant _{Consumption-Rate}	LifeTime _{Residual-Energy}	Queue _{Pending-Tasks}	CurrentState
ID1
ID2
...
...

Figure 10. The structure of the Subordinate Context Data Table

C. Quantitative Module of CASCR

The context data gathered on the time slice are processed according to the 5 states transition rules to get the weights values $\omega_i^{n_j}$ that represent the influence of these context data toward the states' transition respectively. We use the formula fuzzy match theory, Minkowski distance, like equation (1) [17]:

$$d(A, B) = \left[\frac{1}{n} \times \sum_{i=1}^n |\mu_A(u_i) - \mu_B(u_i)|^\sigma \right]^{1/\sigma} \quad (\sigma \geq 1) \tag{1}$$

A relevant standard transition value in an item of the transition rules is defined as S. So we measure the relevant parameters which represent the target node in the first half time slice with the S as the standard. For example, the x_1, x_2, x_3, x_4 , and $U = \{u_1, u_2, u_3, u_4\} = \{x_1, x_2, x_3, x_4\}$ as the universe of discourse then $A = \{\mu_A(u_i) | u_i \in U, i = 1, 2, 3, \dots\}$, $B = \{\mu_B(u_i) | u_i \in S, i = 1, 2, 3, \dots\} = \{1, 1, 1, 1\}$, thereinto, the fuzzy set A represents the degree that u_i approaches to S. The membership function designed in the CASCR is as the formula (2), and it is easy to prove that formula (2) obey a normal distribution.

$$\mu_A(u_i) = e^{-\lambda(u_i - S)^2} \tag{2}$$

$CF(E_i)$ is the key parameters for evaluating a set of evidence's trust degree. An array of data from the reality which represent the states of the nodes to some extent need to be measured by the way of the degree of the jitter of this kind of data in some range. We will turn this set of data down in the trust degree if the jitter extent of the data exceeds our practice to the WSN's work situation, otherwise reversely. This mechanism restricts the relevant weights that participate in the reviewing to the CASCR effectively. The jitter extent of the sample data will be mapped to the relevant trust degree $CF(E_i)$, i.e. the probability determinacy of this set of data evidence in this

samples gathered observation. The CASCR utilizes cloud model theory and improves it proper for the trust degree computing [18-20]. The formula (3), (4), (5),(6) are as below.

$$\widehat{En} = \sqrt{\frac{\pi}{2}} \times \frac{1}{n} \sum_{i=1}^n |X_i - \widehat{E(X)}| \tag{3}$$

$$\widehat{E(X)} = \frac{1}{n} \sum_{i=1}^n X_i \tag{4}$$

$$\widehat{He} = \sqrt{S^2 - \widehat{En}^2} \tag{5}$$

$$CF(E_i) = e^{-\varepsilon \widehat{He}} \tag{6}$$

Thereinto, X_i is the single sample observation value, with S^2 the sample variance and $\widehat{E(X)}$ is sample average, i.e., $\widehat{E(X)} = \bar{X}$. We use the formula (7) to merge the weights of the multi-kinds sample data with the relevant trust degree to obtain $P_{u_i}(E/S)$.

$$P(H_j / S) = P_{H_j}(E / S) = CF_{H_j}(E) = \frac{1}{\sum_{i=1}^n \omega_i^{H_j}} \sum_{i=1}^n (\omega_i^{H_j} \times CF(E_i)) \tag{7}$$

The table of the states transition rules of the nodes is stored in the nodes as Table I.

At last, we forecast the target nodes' transition trend in the future time slice through Markov probability tool. With the equation Chapman-Kolmogorov [21]:

$$P_{ij}(u + v) = \sum_{k=1}^{\infty} P_{ik}(u) P_{kj}(v), \quad i, j = 1, 2, \dots \tag{8}$$

Because the node's state transition rule is matched through fuzzy formula, it means that the next timeslice state is only relative with current situation. So the state transition is a Markov process. We use the relationship $P^{(n)} = P^{(0)^n}$ to calculate the 5×5 state transition matrix.

The results of probability calculated by C-K equation are stored in the Probabilistic or-set table (p-or-set tables for short) [22]. We define the p-or-set table in another way, which makes it more suitable for our algorithm.

N_1	N_2	N_3	N_4	...
$\langle H_{1,1}^1 : P_{1,1}^1, H_{1,2}^1 : P_{1,2}^1, H_{1,3}^1 : P_{1,3}^1, H_{1,4}^1 : P_{1,4}^1, H_{1,5}^1 : P_{1,5}^1 \rangle$	$\langle H_{2,1}^1 : P_{2,1}^1, H_{2,2}^1 : P_{2,2}^1, H_{2,3}^1 : P_{2,3}^1, H_{2,4}^1 : P_{2,4}^1, H_{2,5}^1 : P_{2,5}^1 \rangle$	$\langle H_{3,1}^1 : P_{3,1}^1, H_{3,2}^1 : P_{3,2}^1, H_{3,3}^1 : P_{3,3}^1, \dots \rangle$	$\langle \dots \rangle$	...
$\langle H_{1,1}^2 : P_{1,1}^2, H_{1,2}^2 : P_{1,2}^2, H_{1,3}^2 : P_{1,3}^2, H_{1,4}^2 : P_{1,4}^2, H_{1,5}^2 : P_{1,5}^2 \rangle$	$\langle H_{2,1}^2 : P_{2,1}^2, H_{2,2}^2 : P_{2,2}^2, H_{2,3}^2 : P_{2,3}^2, H_{2,4}^2 : P_{2,4}^2, H_{2,5}^2 : P_{2,5}^2 \rangle$	$\langle \dots \rangle$	$\langle \dots \rangle$	...
...
...	$\langle \prod_{k=1}^5 (H_{j,k}^i : P_{j,k}^i) \rangle$	...	...	...

Figure 11. Probabilistic or-set-table for CASCR

TABLE I. STATES TRANSITION RULES OF THE NODES

EC	CR	RE	PT	Conclusion
<0.5	≤3	>-0.5	<3	H1: transfer to state 1
<0.5	≤3	>-0.5	0	H2: transfer to state 2
0.5~1	3~4	-0.5~-1	>3	H3: transfer to state 3
1~2	4~5	-1~-2	0~5% or >6	H4: transfer to state 4
>2	>5	<-2	0 or >8	H5: transfer to state 5

Definition 9: A p-or-set tables is a probability space in which the set of outcomes \mathbb{S} is finite, and whose outcomes are all the probabilistic counterpart, i.e.,

a pair (\mathbb{S}, p) where $\sum_{H \in \mathbb{S}} p(H) = 1$. Therein,

$$\mathbb{S} := \{H_j \mid j \in [1, 5]\}$$

In each p-or-set table cell the pair is defined as

$$\langle \prod_{k=1}^5 (H_{j,k}^i : P_{j,k}^i) \rangle = \langle H_{j,1}^i : P_{j,1}^i, H_{j,2}^i : P_{j,2}^i, H_{j,3}^i : P_{j,3}^i, H_{j,4}^i : P_{j,4}^i, H_{j,5}^i : P_{j,5}^i \rangle$$

therein, i is the number of rows whereas j is the number of columns, and k presents the state number.

Fig. 11 illustrates the p-or-set table for CASCR. The column number depends on the set size of $Nei(A)$, and the table cells are the probabilistic counterpart where the attribute values are the state transition H_j , and plain probability. In the first cell of Row 2, the content means N_1 has $P_{1,1}^1$ probably transit to State 1, and $P_{1,2}^1$ probably transit to state 2. We can consider the p-or-set table as the Markov state transition matrix, and the number of rows presents the number of order of the transition matrix.

VI. SIMULATION AND RESULT

This paper designs the virtual environment of the simulation experiment based on the physical equipment. It is built according to the real data of the sensor nodes. The CASCR is compared with the classical LEACH and

SPT(shortest path tree) at the aspects of the number of the alive nodes, average energy dissipation and so on. The simulation tool is Matlab 7.8.0 and the environment parameters are in the Table II below.

TABLE II. THE PARAMETERS IN THE SIMULATION ENVIRONMENT

Parameters	Values
area acreage	1500m×1500m
source voltage	3V(DC)
transmitting current	30mA
transmitting power	+0.5dBm
receiving current	37mA
single hop distance	150m
antenna type	omni antenna
number of nodes	50 to 100
power apply capacity/node	60mAh
λ	0.0078
σ	2
ε	0.4621
timeslice	60s
standard queue	10K
data rate of node	250Kb/s
contrastive protocols	LEACH & SPT

The simulation work is comparing with the classical LEACH of the hierarchical routing and the classical SPT of the complanate routing.

As illustrated in Figure 12, we run the protocol with 100 nodes lasting 50 minutes. The survival time of nodes which running CASCR is longer than the other two protocols. In the beginning, CASCR will collect the context information from the neighbor nodes, and that would cause some nodes to consume more energy. So there are some nodes die early in the first 5 minutes. But when the nodes get adequate context information, the CASCR algorithm will be self-optimizing, hence the lifetime of CASCR nodes are two and a half times of SPT and one and a half time of LEACH.

From 10th minute, nodes start to die, and the LEACH and SPT's alive nodes number sharply decline. However, CASCR uses context-ware technology to maintain alive nodes number, and we can see the number of alive nodes running CASCR decline slowly.

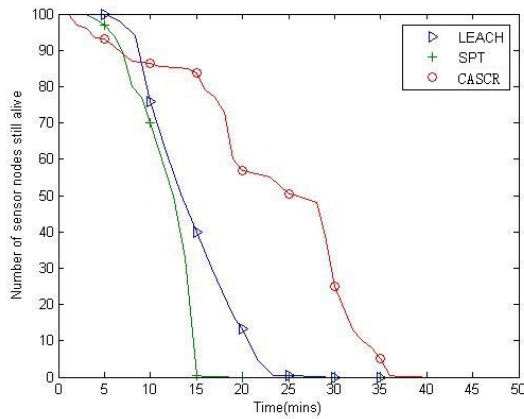


Figure 12. The number of the nodes still alive with time varying in the three protocols

Figure 13 shows the average energy dissipation of the three protocols. From the results, we can see CASCR also has better energy consumption control than the other two. As the discussion above, CASCR's nodes need to collect context information first and calculate through Markov, so its energy consumption in the first 10 minutes is more than LEACH and SPT. But from 10th minute, the energy consumption of CASCR is much lower, which is in accord with the alive node number.

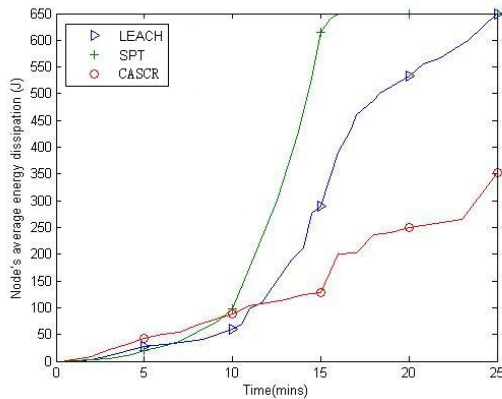


Figure 13. The node's average energy dissipation with time varying in the three protocols

Figure 14 is a comparison in total quantity of the gathered data with the nodes' number varying. We run the three protocols for 20 minutes with 2 nodes increased every time, and the nodes number is increased from 50 to 100. SPT is suited to the small scale network. When the scale of nodes is small, for example less than 60 nodes, the SPT performs the best. However, with the number of nodes increased, SPT's performance descends radically. Since LEACH is a hierarchical routing protocol, when the nodes' scale becomes larger, the performance increases along. For the CASCR, the quantity of the gathered data is one weakness, because in CASCR the nodes have 5 states, including sleeping and hibernating, some nodes may not gather data all the time. But as illustrated in Figure 12, the lifetime of CASCR is 1.5 times of LEACH, and the average quantity of data gathered by LEACH is 1.39 times of CASCR, due to CASCR with long lifetime,

for long-time running CASCR will have a better performance.

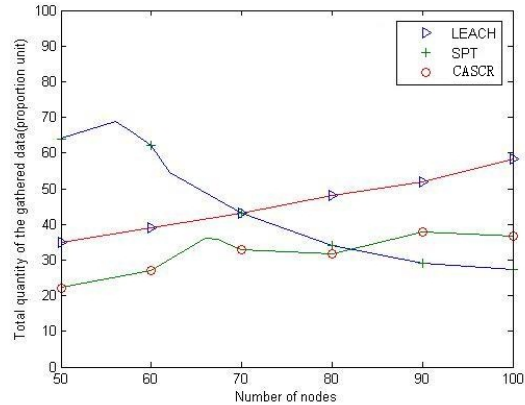


Figure 14. The total quantity of the gathered data with the nodes' number varying in the three protocols

Figure 15 shows the control packet statistic with the number of nodes varying in the three protocols. We run the protocols for 20 minutes with 2 nodes increased every time, and the nodes number is increased from 50 to 100. As illustrated in the figure, the control packet statistic of SPT is always the least, because once the shortest path tree is built, it would not send much control packets. LEACH is a hierarchical routing protocol, and it will always cycle randomly pick the cluster-head node then broadcast the head node's information. So with the increase in the number of nodes, LEACH will send more control packets. For CASCR, the control packets are used to multicast the dynamic context information and the multicast frequency is every half time slice. CASCR is in the middle level, better than LEACH and little worse than SPT. However, SPT's lifetime is short and energy dissipation is high, which makes its performance of it is not good like the other two.

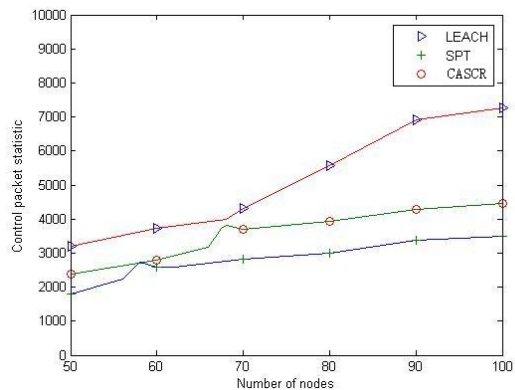


Figure 15. The control packet statistic with the nodes' number varying in the three protocols

The result shows that the CASCR has a better performance to some extent than the other two protocols.

VII. CONCLUSION

In an IOT network, nodes have stronger sensory ability and smarter intelligence. So in this paper we

propose the protocol CASCR as the representative which using the core idea of the context-aware computing into the basis routing protocol. Context information will become more and more important with the development of IOT, because we will not satisfy by gathering the data, but knowing the meaning of the data.

Based on the Sea Computing model, we transform the traditional routing thought into a positive predictable routing protocol with using fuzzy match theory of artificial intelligence and Markov probability model, which contain some forwarding and directive meaning. It is an exploratory evolution direction of the WSN technology in the accordance with the IOT guidance feature in the future.

Through the simulation and analysis of CASCR, the results show that the CASCR has longer life time and lower energy consumption, which indicated that CASCR is more suitable for the IOT routing based on Sea Computing model. But it still has abundant space for improving and the core protocol CASCR proposed here can be improved continuously by the theory circles as a fundamental protocol framework, and can also be enhanced to a cluster-type protocol. We will keep on doing the research on this field.

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