A Study on Off-path Caching Scheme by using Successive Interference Cancellation for Information-Centric Network-based Wireless Sensor Network

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***Abstract*— Recently, advanced WSN (Wireless Sensor Network) technologies, such as IoT (Internet of Things) and M2M (Machine to Machine) are widely applicable to various fields. On the other hand, in the network protocols of future wireless networks, it is required to obtain the sensing data from the summarized monitoring values in the large-scale WSN, i.e., it cannot be efficiently built based on the current host-centric scheme. We should redesign based on the content-centric concept. Under these perspectives, we focus on ICN (Information Centric Network)-based WSN. In particular, in this manuscript, we propose a novel off-path caching scheme by using the overhearing sensing data, and we boost the effort of our off-path caching mechanism by using the SIC (Successive Interference Cancellation) technique. In the numerical results, we reveal that the amount of stored sensing data could increase by using exhaustive Monte Carlo computer simulations. As a result, the proposed scheme can be maximally 3.69 times as improved as the comparable system without using any off-path caching method.**

Keywords-Wireless sensor network; Information-centric network; Off-path caching; Successive interference cancellation.

I. INTRODUCTION

A new WSN (Wireless Sensor Network), such as IoT (Internet of Things) and M2M (Machine to Machine), plays a primary role in providing global access by using billions of various devices. In the WSN, the network protocol, as well as the current Internet infrastructures, are founded upon the host-centric architecture. In the view of evolving traditional network frameworks, the ICN (Information Centric Network) architecture is promoting a new communication model [1]. The ICN architecture is fundamentally different from the traditional IP address-based and host-centric network, i.e., a major concept of ICN is the ability to name data independently from a current location (at which the required sensing data are provided). The ICN-based schemes have been investigated not only in the wired networks, but also in the wireless and mobile networks (including IoT, M2M and WSN) [2][3].

In this manuscript, we focus on a novel caching scheme for the important consideration of ICN-based WSN proposal. Regarding the caching mechanism, there are two common principles, such as the on-path and the off-path caching methods [4]. In the on-path caching, the network exploits information caught along the routing path taken by a name resolution request; while in the off-path caching, the network exploits information caught outside those paths. Regarding the related works for the caching schemes, the traditional ICN frameworks, such as DONA (Data-Oriented Network Architecture) [5] and NDN (Named Data Networking) [6] have natively supported the on-path caching method. The authors in [7] have proposed four on-line intra-domain cache management algorithms and [8] have realized an improvement by using the content-space partitioning and the hash-routing techniques.

In particular, we focus on the off-path caching mechanism. Most researchers have introduced an exclusive mechanism, which popular contents are actively and positively replicated. On the other hand, we effectively utilize the specific wireless feature, such as overhearing phenomena, i.e., when the sensor node transmits the sensing data via the wireless link, its neighbor sensor nodes could receive its sensing data due to the free-space radio propagation regardless of necessary or unnecessary. In other words, the proposed scheme can realize the effective off-path caching mechanism without using alternative exclusive data packets and another wireless communication module. Note that, although the signal processing for receiving and decoding transactions need additional energy consumptions, their electrical power is sufficiently smaller than the radio transmission power. Therefore, the cost of extra power consumption could be ignored, unlike the wired network system.

Moreover, regarding the signal processing of overhearing transactions, we utilize the SIC (Successive Interference Cancellation) technique [9] in order to boost the off-path caching capability. Under the SIC-based system, the receiver side tries to decode the strongest signal in the parallel signals from several transmitter sides. If the strongest signal can be successfully decoded, the decoded signal is encoded again and is subtracted from the received signal. Thus, the decoding performance of remaining signal can be improved by removing the strongest interference. The SIC technique has been extensively studied as the physical layer technology; whereas, its performance and behavior in the ICN-based wireless sensor network remain unknown, i.e., our study can demonstrate significant preliminary evaluations.

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The rest of this paper is organized as follows. Section II describes the proposed scheme. Section III provides the computer simulation results. Finally, the acknowledgment and conclusions close the article.

II. PROPOSED SCHEME

As shown in Figure 1, the sensor nodes are distributed in the observation area, and every sensor node measures the environmental monitoring values as the sensing data. In the ICN-based system, there is no difference between the original and replicate information when other sensor node requests the same sensing data. Therefore, similar to the traditional ICN studies, the proposed scheme establishes the data transmission link between the subscriber and publisher nodes (that is the routing path). We define the sensor node who transfers and forwards the sensing data along the routing path as the relay node. According to the ICN principles, the relay nodes store the forwarding data into their cache memory as the on-path caching transaction in order to effectively respond to the sensing data in case of a duplicated scenario.

On the other hand, regarding the SIC method, let $P_{i,j}$ denote the signal strength at the j-th sensor node (that is receiver node) based on the overhearing processing from the i-th sensor node (that is a relay node) and let $\mathcal{M}_j$ denote the set of concurrent transmitting sensor nodes that can be heard by the j-th sensor node. If the signal from the i-th sensor node to the j-th sensor node can be decoded correctly, $P_{i,j}$ is satisfied with

$$\mathcal{H}: \frac{P_{i,j}}{\sum_{k\in\mathcal{M}_j}^{k\neq i} P_{k,j}+\sigma^2} \geq \beta \tag{1}$$

where β is the power level of required received signal threshold and σ^2 is the power of ambient noise, respectively. In short, (1) indicates that the j-th sensor node can store the replicated data of the i-th sensor node, if the SINR (Signal to Interfealance plus Noise Ratio) is sufficiently large.

As shown in Figure 2, let y denote the j-th sensor node's received signal strength, which is expressed as

$$y = \sum_{m=1}^{M_j} P_{m,j} \tag{2}$$

where M_j is the amount of $\mathcal{M}_j$'s elements. In the proposed scheme, the decoder works to recover the strongest signal among the input signals (such as the received signal in the first transaction). Therefore, the j-th sensor node tries to decode the signals based on (1), the received signal can be decoded correctly if and only if

$$\begin{aligned} &\text{Step1:} && \frac{\hat{y}_1}{y} = \frac{P_{1,j}}{\sum_{m=1}^{M_j-1} P_{m,j}+\sigma^2} \geq \beta \\ &\text{Step2:} && \frac{\hat{y}_2}{y-y_1} = \frac{P_{2,j}}{\sum_{m=1}^{M_j-2} P_{m,j}+\sigma^2} \geq \beta \\ &\quad\vdots && \qquad\vdots \\ &\text{Step } K\text{:} && \frac{\hat{y}_K}{y-\sum_{k=1}^{K-1} y_k} = \frac{P_{K,j}}{\sum_{m=1}^{M_j-K} P_{m,j}+\sigma^2} \geq \beta \end{aligned} \tag{3}$$

where K denotes the number of successful decoded signals, $\hat{y}_k$ and y_k denote the correct decoded signal and the reconstructed transmission signal based on the decoded signal, respectively. In (2) and (3), we assume that both y_k and $P_{m,j}$ are non-decreasing order as $y_1 \geq y_2 \geq \cdots \geq y_K$ and $P_{1,j} \geq P_{2,j} \geq \cdots \geq P_{K,j}$, respectively.

If we realize the SIC mechanism as shown in Figure 2, we should formulate the detailed protocol design. However, its consideration is out of scope because of analyzing the principal evaluation in this paper. In particular, the considered scheme (with the above terms) should adaptively switch based on the sensor node status, such as not only transmission and receiving modes but also the overhearing mode, which is our future works.

III. NUMERICAL RESULT

Regarding the radio propagation model, we ignore the multi-path fading and shadowing to avoid system complexity. Therefore, the received signal strength can be calculated based on

$$P_{\mathrm{RX}} = P_{\mathrm{TX}} - L_{\mathrm{TX}} + G_{\mathrm{TX}} - L_{\mathrm{P}} + G_{\mathrm{RX}} - L_{\mathrm{RX}} \quad (\mathrm{dB}) \tag{4}$$

where P_{TX} and P_{RX} are the electrical radio powers, L_{TX} and L_{RX} are the circuit power losses, and G_{TX} and G_{RX} are the antenna gains at the transmitter and receiver terminals, respectively. We determine the above parameters (without P_{RX} and L_{P}) based on the familiar XBee RF module [10]. As shown in Table I, we illustrate the simulation parameters (including above constant values). Note that, the circuit losses at transmitter and receiver sides are not taken into account to avoid system complexity, which occurs in case of the impedance mismatching and power losses at physical circuits as the thermal noise.

In (4), L_{P} is the radio-wave attenuation, which we can calculate L_{P} based on the ratio propagation model [11] with

$$L_{\mathrm{P}} = A + 10\gamma \log_{10}(d/d_0) \tag{5}$$

and

$$A = 20 \log_{10}(4\pi d_0/\lambda) \tag{6}$$

and

$$\gamma = a - bh_0 + c/h_0 \tag{7}$$

where d is the distance between sensor nodes, λ is the radio wavelength, h_0 is the antenna height, and d_0, a, b and c are the constant values depending on the surround environments (see Table I) that are given by [11].

In the computer simulation, the sensor nodes are randomly scattered and the pair of publisher and subscriber nodes is randomly selected. The routing path between the publisher and subscriber nodes is decided based on the minimum physical distance. For eliminating the calculation costs, we utilize the Dijkstra's algorithm [12] (whose algorithm can obtain the optimal path to minimizing the weight links). Regarding the SIC method, we calculate the signal strength based on the distance among sensor nodes, and we assume that the SIC mechanism are ideally conducted and worked.

Figure 3 shows the number of sensor nodes, N, versus the ratio between the sensor nodes that can correctly store the overhearing data and the overall sensor nodes, ρ. As a result, ρ is improved depending on increasing of N, because of increasing the sensor nodes that can store with the overhearing transactions due to increasing a densely deployment. In the case when $170 \leq N$ region, ρ maintains a constant value because of reaching the upper limitation. In comparison with the comparable scheme (without using the off-path caching method), our scheme can improve by 251%, 284%, 341% and 369% at N = 50, 100, 150 and 200, respectively.

IV. CONCLUSION

In this paper, we proposed a novel caching mechanism with the overhearing phenomena and SIC techniques for ICN-WSN. Computer simulation demonstrated that the proposed scheme could have a maximum of 3.69 times improvement over the comparable scheme. In future works, we should consider the detailed protocol design, and demonstrate and discuss under a realistic environment.

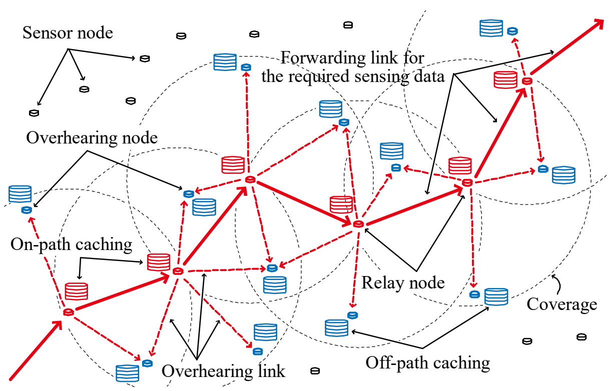

Figure 1. Overview of the proposed scheme.

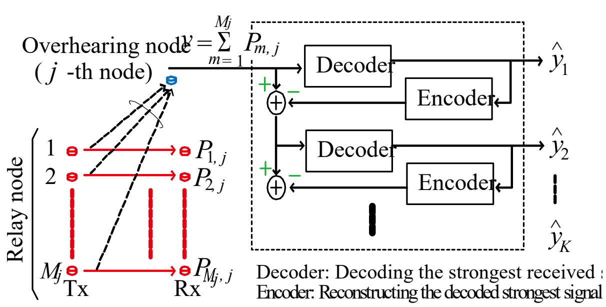

Figure 2. Procedure of SIC process for the proposed caching scheme.

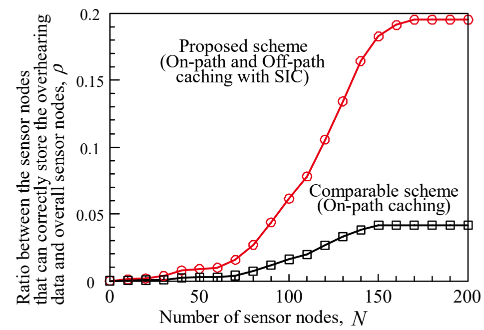

Figure 3. Number of sensor nodes versus the sensor nodes that can correctly store the overhearing data over the number of all sensor nodes.

TABLE I. SIMULATION PARAMETERS

Terms	Values
Transmission power	P_{TX} = 0 dBm (1mW)
Circuit power loss	L_{TX} = 0dB, L_{RX} = 0 dB
Antenna gain	G_{TX} = 0 dBi, G_{RX} = 0 dBi
Parameters in [11]	d_0 = 100, a = 3,6, b = 0.005, c = 20
Antenna height	h_0 = 0.5 m
Radio frequency	2.4 GHz (λ = 0.125 m)
Observation area	1,000 m × 1,000 m
Amount of Pub./Sub. node pair	10

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