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Reducing Phase Cancellation Effect with ASK-PSK Modulated Stamp in Augmented UHF RFID Indoor Localization System

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Abstract

In this paper, we propose exploiting ASK-PSK modulated stamp in receiving path selection technique to lessen the phase cancellation effect in augmented ultra-high-frequency (UHF) radio frequency identification (RFID) indoor localization system (AURIS). In AURIS, a tag-like semi-passive RFID component (referred as sensatag) can capture backscatter signal of other proximal tags with presence of RF source. According to the principle of backscatter radio link, the received signal at sensatag antenna is the superposition of backscatter signal of tags and continuous carrier wave (CW) from RF source. However, due to phase difference between tag's backscatter signal and RF CW, the modulated backscatter signal could be cancelled. We refer this effect as phase cancellation effect. Exploiting the spatial diversity of dual-antenna's two receiving paths, the likelihood of phase cancellation occurrence could be reduced. But the developed technique with two co-operating paths is not energy efficient. Therefore, this paper proposes to inject a ASK-PSK modulated stamp sequence in the pilot tone of backscatter signal as a signature of phase cancellation for ASK modulated data frame, which could be identified by the receiving sensatag. With the knowledge of occurrence of phase cancellation, sensatag could activate the alternative receiving path. This technique fully exploits the space diversity of dual-antenna, and also reduces the power consumption by reducing one receiving path in operation. We demonstrate the performance of stamp based receiving path selection technique with data obtained from computer simulation.

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Keywords: Augmented UHF RFID indoor localization system (AURIS); phase cancellation; ASK-PSK modulated stamp

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1. Introduction

Conceptually, Internet-of-Things (IoT) means "who", "where" and "how" of physical objects, such as books in libraries, medicine boxes in pharmacy stores, and commodities in warehouses[1]. Such concept demonstrates the omnipresent need of seamless localization capability for physical objects in the IoT paradigm. Since the popular satellite-based localization services to date are restricted to outdoor environment, indoor localization has become the focus of research during the past decades. Recently, ultra-high-frequency (UHF) radio frequency identification (RFID)-based indoor localization technique has attracted much attention due to its advantages in terms of low-cost, ease-deployment and free-maintenance[2]. The majority of state-of-the-art UHF RFID localization techniques explored extracting location information from prorogation characteristics of RF signal returned to readers from tags. However, due to the

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non-line-of-sight conditions, multipath distortion and fast temporal changes of indoor environment, the overall accuracy and robustness of these techniques are low[3].

One direction for addressing this problem is to apply proximity-based method. Proximity-based methods employ a different approach, and they rely on using binary information related to whether the target is within references's proximity[3]. Several proximity-based solutions have been proposed by researchers. However, neither the reader-based[4] nor the augmented device-based[5 6 7] solutions are mature and cost-effective for IoT application[8].

In our previous work, an EPCglobal Class1 Gen2-compliant semi-passive UHF RFID component (referred to as sensatag) is proposed[9]. Sensatag has a dual functionality: it is capable of sensing the backscatter communication between reader and tags within its proximity; and it can also conduct backscatter communication with the reader like standard passive tags. This unique functionality allows for the development of proximity-based accurate localization system[3]. Furthermore, incorporating ad-hoc style communication protocol sensatags have the potential to communicate among themselves in a multihop fashion with presence of RF exciter. Enabled by such advancement, sensatag-based indoor localization system would be improved significantly in flexibility, scalability and cost effectiveness. The model of the novel augmented UHF RFID indoor localization system (AURIS) is as following: a) sensatag ad hoc network part is designed to conduct coarse localization based on the connectivity information among sensatags; b) Gen2 reader-based localization system part is designed for accurate localization following Gen2 protocol and sensatag locator protocol[9].

Backscattering communication paradigm leverages passive tag from the impedance of power-hungry active radio. In Gen2 reader-based system part, the reader does not turn itself off but instead transmits continuous CW during the time passive tags backscatter information to the reader. A destructive phase cancellation effect happens[10], in which the modulated tags' backscattering signal at sensatag's antenna could be cancelled out due to the phase difference between backscattering and reader's CW. To counter phase cancellation effect we applies dual-antenna based techniques such as simple combination and receiving path selection technique. Since the receiving path selection technique exploits fully spatial diversity provided by two antennas, it performs better than the simple combination technique[11].

Correspondingly, phase cancellation is also a problem in sensatag ad hoc network part, since sensatag-to-sensatag communication is via backscattering as well. Dual-antenna based receiving path selection technique is feasible to combat phase cancellation in this case. However, due to multihop fashion of the network, the jump of power consumption is a major issue for sensatag compared with that of Gen2 reader-based part. Receiving path selection technique performs simple selection algorithm on two co-operating receiving paths, which is designed for complying with standard UHF RFID system. However, in sensatag ad hoc network, such technique would lead to unnecessary power consumption. Unlike passive tags, sensatag would be capable to inform the occurrence of phase cancellation to the receiving sensatag with simple modification. This paper proposes to inject an amplitude shift keying (ASK)-phase shift keying (PSK) modulated stamp to the pilot tone of transmitting sensatag's backscattering signal. The receiving sensatag decides on activating one of the two receiving paths in digital section based on the captured stamp. Adopting this technique allows only one receiving path of sensatag's digital section to operate for each communication round. We conducted the experiment in our newly developed UHF RFID simulator. Simulation results demonstrate that the proposed technique reduces the probability of phase cancellation as much as receiving path selection technique.

The paper is organized as follows. In next section, we briefly describe phase cancellation effect and receiving path selection technique. In section 3, we introduce ASK-PSK modulated stamp mechanism. The results of performance simulation are provided in Section 4. In Section 5, we conclude the paper and discuss the future work.

2. Problem formation

Phase cancellation effect originates from the nature of backscattering modulation and the unique design of sensatag. As for Gen-2 reader based system, in *Listening* state the signal at sensatag's antenna is the superposition of reader's transmitting CW and tag's backscattering signal. Let's assume A_R is the amplitude of reader CW at the sensatag antenna, A_{T1} and A_{T2} are the amplitude of the tag backscattering for two different radar cross section (RCS) states. In this case the tag applies ASK modulation. θ is the phase difference between reader CW and tag's backscattering signal. Using a simple passive envelope detector, the amplitude of resultant received signal for the two states are represented by A_1 and A_2 respectively. Fig.1 pictorially demonstrates the amplitude difference $|A_1 - A_2|$ varies depending on θ. The phase cancellation occurs when $A_1 = A_2$. Besides that, PSK modulated backscattering communication link also suffers from such destructive effect[10].

(a) Without phase cancellation (b) With phase cancellation

Fig. 1. Phasor diagram that shows superimposed signal at the sensatag antenna

To overcome the phase cancellation problem, our previous work proposed a receiving path selection technique to fully exploit the spatial diversity of two antennas[11]. The philosophy behind this technique is straightforward. As in Fig.2 sensatag has two parallel fully functional receiving paths based on envelope detection technique. When the phase cancellation occurs, the baseband data feed into digital section is cancelled. The simple selection algorithm is shown in Algorithm.1. From the Monte Carlo simulation result, receiving path selection technique reduce the probability of phase cancellation effect to a negligible degree of under 1%.

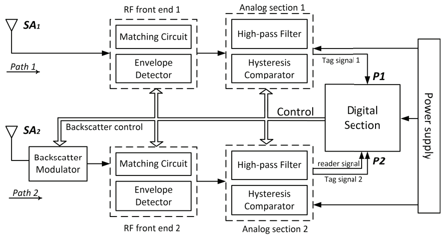


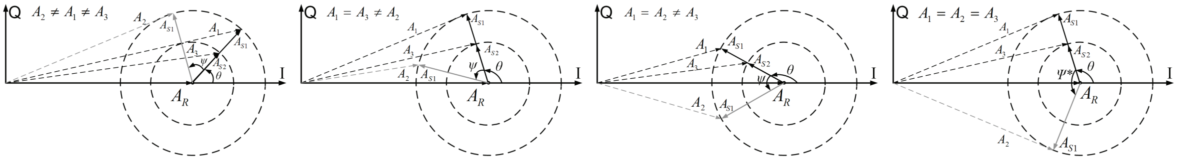
Fig. 2. Block diagram of sensatag

```
Require: P1,P2 from analog section
ID1=Decode(P1); ID2=Decode(P2);
procedure SELECTION(ID1, ID2)
    if ID2 != NULL then
        return (ID2)
    else
        return (ID1)
    end if
end procedure
```

Algorithm 1. The selection algorithm

In Gen-2 reader based system part, all the workload of countering phase cancellation lies at sensatag's two co-operating receiving paths, since the off-the-shelf passive tags and reader have no capability to inform about the occurrence of phase cancellation. However, in sensatag ad hoc network sensatag could acquire such knowledge in advance with minor hardware modification. This type of technique could fully exploit the spatial diversity of dual antennas, while converting the co-operating dual paths to alternating single path. It is reasonable to anticipate the power consumption of sensatag would be reduced in considerable amount.

3. ASK-PSK modulated stamp



(a) No phase cancellation (b) Phase cancellation for ASK (c) Phase cancellation for PSK (d) Phase can. for ASK-PSK

Fig. 3. Phasor diagram that shows superimposed signals at receiving sensatag antenna for ASK-PSK backscatter modulation

In off-the-shelf UHF RFID systems, the backscatter link employs either ASK or PSK backscatter generated by a two-state modulation of the impedance presented to the transponder's antenna[12]. Employing multiple FET switches along with multiple load impedances, passive RFID components could perform M-ary modulation, such as arbitrary QAM[13]. Thus with three FET switches and two impedances, sensatag could conduct ASK and PSK modulation in the backscattering communication link in the same frame. The probability of phase cancellation problem occurs for two types of modulation in the same frame is minimal. Therefore, in sensatag-to-sensatag communication link a ASK-PSK modulated stamp in the pilot tone could be used as the signature of phase cancellation effect.

The model for the ASK-PSK modulated backscatter signal is as following. Let A_R denote the amplitude of external RF exciter's CW signal received at the receiving sensatag antenna. Let A_{S1} and A_{S2} be the amplitude of the transmitting sensatag backscatter in two states of ASK modulation measured at the receiving sensatag antenna. The amplitude of the signal backscattered by the transmitting sensatag in PSK modulation remains the same as A_{S1}, while ψ is the phase difference of backscatter signal in two states. Let θ be the phase difference between the RF exciter signal and the transmitting sensatag signal in one of three states as measured at the receiving sensatag antenna. Then the resultant signal at the receiving sensatag antenna in three states are S_1, S_2 and S_3 respectively. Correspondingly, the amplitude of the signals detected by the envelope detector are A_1, A_2 and A_3.

$$\begin{aligned} S_1 &= A_R e^{j\omega t} + A_{S1} e^{j(\omega t+\theta)} \\ S_2 &= A_R e^{j\omega t} + A_{S1} e^{j(\omega t+\theta+\psi)} \\ S_3 &= A_R e^{j\omega t} + A_{S2} e^{j(\omega t+\theta)} \end{aligned} \quad \Rightarrow \quad \begin{aligned} A_1 &= \sqrt{A_{S1}^2 + A_R^2 + 2A_R A_{S1}\cos\theta} \\ A_2 &= \sqrt{A_{S1}^2 + A_R^2 + 2A_R A_{S1}\cos(\theta+\psi)} \\ A_3 &= \sqrt{A_{S2}^2 + A_R^2 + 2A_R A_{S2}\cos\theta} \end{aligned} \tag{1}$$

The ability of sensatag to detect backscattering signal depends on the small change of the superimposed signals' amplitude. The larger this change is, the higher is the likelihood that the receiving sensatag will detect transmitting sensatag's backscatter. The values of amplitude change for ASK and PSK are respectively

$$\begin{aligned} |A_1 - A_3| &= \frac{|A_{S1} - A_{S2}||A_{S1} + A_{S2} + 2A_R\cos\theta|}{\sqrt{A_{S1}^2 + A_R^2 + 2A_R A_{S1}\cos\theta} + \sqrt{A_{S2}^2 + A_R^2 + 2A_R A_{S2}\cos\theta}} \\ |A_1 - A_2| &= \frac{2A_R A_{S1}|cos\theta - cos(\theta+\psi)|}{\sqrt{A_{S1}^2 + A_R^2 + 2A_R A_{S1}\cos\theta} + \sqrt{A_{S1}^2 + A_R^2 + 2A_R A_{S1}\cos(\theta+\psi)}} \end{aligned} \tag{2}$$

Complete phase cancellation for ASK will happen when $A_1 = A_3$, and for PSK when $A_1 = A_2$.

$$\begin{aligned} \theta_{\text{cancel,ASK}} &= \arccos(-\frac{A_{S1} + A_{S2}}{2A_R}) \\ \theta_{\text{cancel,PSK}} &= -\frac{\psi}{2} + k\pi, \quad \text{where k is integer} \end{aligned} \tag{3}$$

The condition of phase cancellation for both types of modulation is satisfied by $\theta_{\text{cancel,ASK}} = \theta_{\text{cancel,PSK}}$ with ceratin combination of A_{S1}, A_{S2}, A_R and ψ, which depends on transmitting sensatag's RCSs, RF exciter's transmitting power, as well as relative positions of RF exciter, transmitting and receiving sensatag antennas.

Fig.3 shows the phasor diagram of the superimposed signal at receiving sensatag antenna according to Formula 1. The dotted circles represent the locus of A_{S1}, A_{S2} with varying θ. Fig.3(a) depicts an example with no phase cancellation for either ASK or PSK. The envelope amplitude A_1 and A_3, A_1 and A_2 are not equal, thus the receiving sensatag could detect two types of modulation. Fig.3(b) and Fig.3(c) depict the example with phase cancellation for one type of modulation schemes ASK and PSK respectively. The examples above apply one set of ASK-PSK modulated signal parameters A_{S1}, A_{S2} and ψ. Fig.3(d) depicts one example with phase cancellation for both ASK and PSK modulation with a different set of signal parameters A_{S1}, A_{S2} and $\psi*$.

Theoretically, the phase cancellation condition for both modulation schemes could be avoided with certain backscatter modulation design, e.g. $\psi = \pi$. However, the RCS of passive backscatter modulator is highly frequency-dependent, nonlinear and fast time variant due to modulation[14]. Therefore, the probability of phase cancellation for both modulation schemes could not be eliminated, but the likelihood of the occurrence of such type phase cancellation would be extremely low according to Formula 3. Thus a ASK-PSK modulated stamp in pilot tone could serve as the signature of phase cancellation for receiving sensatag. Once detecting the occurrence of phase cancellation for ASK modulation in stamp, sensatag could switch to the alternative receiving path. It is reasonable to assume the phase cancellation effect would be lessened. In next section, we would verify the performance of ASK-PSK modulated stamp through simulation.

4. Simulation analysis and results

The sensatag-to-sensatag communication link is modelled in our newly developed Proximity-detection-based augmented RFID system simulator (PASS)[10 11]. PASS is a MATLAB-based time-domain system-level simulator designed for UHF RFID system, which is based on position aware RFID system (PARIS) simulator[14]. Basic structure of PASS is organized in a modular and hierarchical fashion.

From PARIS simulator, PASS inherits the behavior model of a NXP UCODE G2XM passive tags and wireless channel. The functionality of generic reader is implemented according to ISO 18000-6C. RF exciter shares the physical model with reader while discarding the intelligence section. The sensatag model is developed to simulate the specific device in Fig.2. The reflection coefficient of sensatag is determinant for backscatter communication modelling, since it is the physical parameter bridge between sensatags. The reflection coefficient is frequency dependent, non-linear and time variant, which is provide by a 2-D lookup table. The reflection coefficient model of sensatag is borrowed from the tag model of PARIS, which is extensive measured and verified. The model's main drawback is that the supported modulation scheme is ASK alone.

Fig.4 depicts the experiment setup to evaluate the feasibility of ASK-PSK modulated stamp in reducing phase cancellation effect. The RF exciter antenna is placed at the origin (0,0) of the area. The trajectory of the transmitting sensatag is along x-axis from (1,0) to (7,0) in the increment of 0.5 m. The position of receiving sensatag is uniformly distributed over the circle centering at the transmitting sensatag and with the radius of 0.5m. An instance of the experiment for one transmitting sensatag and its associated receiving sensatag's sampling positions is referred as a cell. In a cell there are 300 possible positions for receiving sensatag which are sampled by Monte Carlo method based on uniform distribution. The experiment scenario is established in PASS.

The test stamp frame format in simulation is shown in Fig.5, followed by the data frame as 10 bits '0' in Miller 2 modulated by ASK. The phase difference of two PSK states are separated by the ideal 180°. In Algorithm.2 the stamp selection algorithm detects the phase cancellation occurrence for data frame's ASK modulation with the ASK-PSK modulated stamp. The output of decoded module is '-' when phase cancellation occurs. As the decoded stamp matches the phase cancellation pattern, the selection algorithm activates the switch procedure from receiving path *P2* to *P1*.

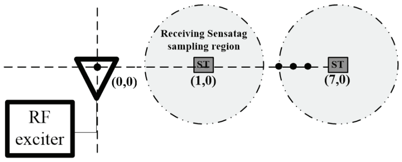


Fig. 4. Experiment setup

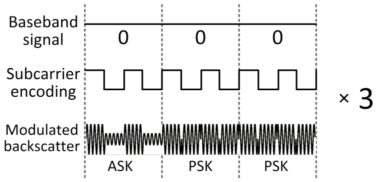


Fig. 5. ASK-PSK modulated stamp

In the first set of experiment, we measure the signal parameters for ASK and PSK modulation respectively. The output of the envelope detector servers as the indicator for phase cancellation, and the threshold of phase cancellation is set at 0.005V. The purpose of the experiment is to validate the mathematical model derived in Section 3. We conducted the simulation trail, and captured the cases for four situations, which includes no phase cancellation, phase cancellation for ASK alone, phase cancellation for PSK alone, and phase cancellation for both. The measured physical quantities are presented in the left columns of Table1. Based on these measurements of signals, we could calculate $|A_1 - A_2|$, $|A_1 - A_3|$, $\theta_{\text{cancel,ASK}}$ and $\theta_{\text{cancel,PSK}}$. The calculated results are presented in the right columns of the table. The simulation result for these four cases are in agreement with proposed mathematical model.

Table 1. The measured values of physical quantities and calculation results.

Case index	A_R(V)	A_{S1}(V)	A_{S2}(V)	ψ(rad)	θ(rad)	$\lvert A_1 - A_3\rvert$ (V)	$\lvert A_1 - A_2\rvert$ (V)	$\theta_{\text{cancel,ASK}}$ (rad)	$\theta_{\text{cancel,PSK}}$ (rad)
No phase can.	0.0953	0.0327	0.314	3.1416	0.0874	0.0013	0.0215	1.9138	1.5708
Phase can. for ASK	0.0372	0.0167	0.0149	3.1416	2.2086	0.00037	0.0075	2.0122	1.5708
Phase can. for PSK	0.0437	0.0284	0.0265	3.1416	1.5703	0.0010	0.000014	2.2500	1.5708
Phase can. for both	0.1084	0.0237	0.0224	3.1416	1.5232	0.00032	0.00045	1.5377	1.5708

the measurements are in agreement with Formula (1), (2) and (3).

In the second set of experiment, we studied the probability of phase cancellation for ASK and PSK modulation scheme. As in the simulation setup in Fig.4, we conducted experiment through 3900 sampling positions in 13 cells. We repeated the experiments three times with different Monte Carlo sampling. The probability of phase cancellation for two types of modulation is shown in Fig.6. Note that the decline phenomenon of phase cancellation probability for ASK with increasing distance is due to the power level of incident RF exciter CW and saturation of sensatag's ASK backscatter modulator. Meanwhile, the increasing phenomenon for PSK is due to the decreasing reflection coefficients of sensatag backscatter modulator. The phase cancellation occurs for both ASK and PSK in one frame is extremely low, and it is 0.77‰

In the third set of experiment, we explored the anti-phase cancellation performance of ASK-PSK modulated stamp based dual-antenna selection technique, and compared with the single antenna implementation and original receiving path selection technique. In simulation, the ASK-PSK stamp based selection technique follows the selection algorithm Algorithm.2. The output of sensatag's envelope detector for ASK modulated 10-bits data serves as the indicator of anti-phase cancellation performance of ASK-PSK stamp based technique. We conducted the experiment in 13 cells for 3 times. In Fig.7, the probability of phase cancellation for three techniques is presented. The performance of two dual-antenna based techniques are at the same level. The difference of overall probability for these two techniques is below 0.1‰.

```
Require: 9 bits stamp S(1:9) from P2
procedure SWITCH=SELECTION(S)
    for i=1, n=0; i < 9; i+=3 do
        if S(i:i+2)==“-00” then
            n++;
        end if
    end for
    if n ≥ 2 then
        return (1);
    else return (0);
    end if
end procedure
```

Algorithm 2. The stamp selection algorithm

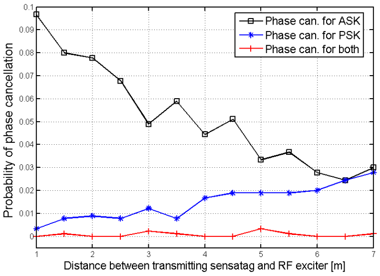


Fig. 6. Probability of phase can.

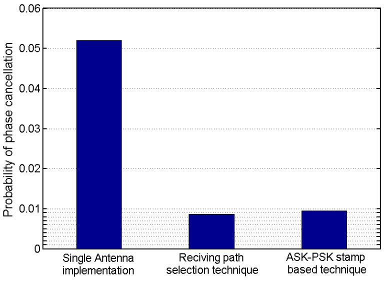


Fig. 7. Anti-phase can. performance

5. Conclusion

In this paper, we investigate the feasibility of ASK-PSK modulated stamp serving as the signature of phase cancellation in AURIS. The simulation results show that the stamp based technique maintains the same level anti-phase cancellation performance as the receiving path selection technique, Meanwhile, the two co-operating receiving paths are reduced to a single alternative operation path, which is more energy efficient.

For the ongoing research there are three directions. The first is to design the pattern of ASK-PSK modulated stamp, with which the anti-phase cancellation performance of the proposed technique would be increased. The second is to design and develop the ASK-PSK stamp based technique in programmable sensatag. The responsiveness would be a focus. The third is to evaluate power consumption of the stamp based technique. We roughly estimate power consumption of current FPGA Spartan-3 embedded implementations in Xilinx Power Estimator (XPE), the dynamic power consumption of one operating receiving path implementation is 79 mW, while that of two co-operating receiving paths is 94 mW. Thus ASK-PSK stamp based technique is promising in increasing the power efficiency.

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