EMIT: Reflection-based Charging Jamming Attack

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1 PROOFS

THEOREM 4.1. *When the reflector is placed at the innermost destructive ellipse of sensor s_i, selecting any vertex as the reflector's placement position will result in the maximum attack effect, while choosing any co-vertex as the placement position will yield the minimum attack effect.*

PROOF. Note that the amplitude of the wave will be inevitably attenuated during reflection, and the reflected wave experiences greater propagation attenuation compared to the wave from the MC. Thus, the power of the reflected wave arriving at the sensor must be lower than that of the wave from the MC. To achieve the maximum attack effect, we need to maximize the power of the reflected wave reaching the sensor.

The following equation expresses the reflected wave arrived at sensor s_i:

$$A_R(t) = \frac{\Gamma A_0}{\hat{d}_{MC,R}} \cos(\phi_0 + 2\pi f t - \frac{2\pi}{\lambda} d_{MC,R} - \pi). \tag{1}$$

Then, we can calculate the power of the wave from reflector R reaching sensor s_i as:

$$P_{R,s_i} = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} [A_{R,s_i}(t)]^2 \mathrm{d}t = \frac{\Gamma^2 A_0^2}{2\hat{d}_{MC,R}^{\,2} \hat{d}_{R,s_i}^{\,2}}. \tag{2}$$

Thus, we can see that the power P_{R,s_i} is determined by $\hat{d}_{MC,R}^{\,2}\hat{d}_{R,s_i}^{\,2}$. Based on the geometric properties of ellipse, no matter where the reflector is deployed at the innermost destructive ellipse, the value of $d_{MC,R} + d_{R,s_i}$ remains constant, equivalent to $\hat{d}_{MC,R} + \hat{d}_{R,s_i}$ being constant. Consequently, by maximizing the difference between $\hat{d}_{MC,R}$ and $\hat{d}_{R,s_i}$, we can minimize $\hat{d}_{MC,R}^{\,2}\hat{d}_{R,s_i}^{\,2}$, thereby maximizing the reflected power reaching the sensor. Thus, to achieve the maximum attack effect, we should place the reflector at any vertex of the innermost destructive ellipse. Conversely, placing the reflector at any co-vertex of the ellipse results in the difference between $\hat{d}_{MC,R}$ and $\hat{d}_{R,s_i}$ being zero, thus minimizing the reflected power reaching the sensor. Hence, the theorem is proven. □

THEOREM 4.3. *Let $\widetilde{U}_{l_j}^R$ denote the approximated overall charging utility of set S_{l_j}, and $U_{l_j}^R$ denote the overall charging utility of S_{l_j}. The approximation error is*

$$\frac{|\widetilde{U}_{l_j}^R - U_{l_j}^R|}{\widetilde{U}_{l_j}^R} \le \epsilon,\ (0 < \epsilon < 1). \tag{3}$$

PROOF. According to Lemma 4.2, $\frac{|\widetilde{P}_{s_i}(\phi) - P_{s_i}(\phi)|}{\widetilde{P}_{s_i}(\phi)} \le \epsilon$, for a single sensor s_i, there are three cases to be considered:

- Case (1): $\widetilde{P}_{s_i}(\phi) \le P_{s_i}(\phi) \le P_{th}$, $P_{s_i}(\phi) \le \widetilde{P}_{s_i}(\phi) \le P_{th}$;
- Case (2): $\widetilde{P}_{s_i}(\phi) \le P_{th} \le P_{s_i}(\phi)$, $P_{s_i}(\phi) \le P_{th} \le \widetilde{P}_{s_i}(\phi)$;
- Case (3): $P_{th} \le \widetilde{P}_{s_i}(\phi) \le P_{s_i}(\phi)$, $P_{th} \le P_{s_i}(\phi) \le \widetilde{P}_{s_i}(\phi)$.

For Case (1), $u(P_{s_i}(\phi)) = \frac{P_{s_i}(\phi)}{P_{th}}$, $u(\widetilde{P}_{s_i}(\phi)) = \frac{\widetilde{P}_{s_i}(\phi)}{P_{th}}$, according to Lemma 4.2, the conclusion obviously stands.

For Case (2), if $\widetilde{P}_{s_i}(\phi) \le P_{th} \le P_{s_i}(\phi)$, then $u_{(P_{s_i})} = 1$, $\frac{|u(\widetilde{P}_{s_i}(\phi))-1|}{u(\widetilde{P}_{s_i}(\phi))} \le \frac{|u(\widetilde{P}_{s_i}(\phi)) - \frac{P_{s_i}(\phi)}{P_{th}}|}{u(\widetilde{P}_{s_i}(\phi))}$; if $P_{s_i}(\phi) \le P_{th} \le \widetilde{P}_{s_i}(\phi)$, then $u(\widetilde{P}_{s_i}(\phi)) = 1$, $\frac{|1-u(P_{s_i}(\phi))|}{u(\widetilde{P}_{s_i}(\phi))} \le \frac{|\frac{\widetilde{P}_{s_i}(\phi)}{P_{th}} - u(P_{s_i}(\phi))|}{u(\widetilde{P}_{s_i}(\phi))}$, so, Case 2) stands too.

For Case (3), $u(P_{s_i}(\phi)) = 1$, $u(\widetilde{P}_{s_i}(\phi)) = 1$, $\frac{|u(\widetilde{P}_{s_i}(\phi)) - u(P_{s_i}(\phi))|}{u(\widetilde{P}_{s_i}(\phi))} = 0 < \epsilon$, the conclusion stands. In all, for a single sensor, the conclusion stands, so for the all sensors in set S_{l_j}, the conclusion still stands. □

LEMMA 5.1. *No matter where the MC stays within the potential charging area, one vertex of its innermost destructive ellipse formed by the target sensor and the MC always lies on a circle with a radius $\frac{\lambda}{2}$ and the target sensor as the center.*

PROOF. Note that, for any one vertex of the innermost destructive ellipse, it always satisfies $d_{MC,vertex} + d_{vertex,s_{target}} - d_{MC,s_{target}} = \lambda$. For the vertex closer to s_{target}, since $d_{MC,vertex} = d_{MC,s_{target}} + d_{vertex,s_{target}}$, the distance between the sensor and the vertex is $\frac{\lambda}{2}$. Thus, we can conclude that no matter the location the MC is, the distance between the target sensor and the vertex is always equal to $\frac{\lambda}{2}$. The lemma is proven. □

THEOREM 5.2. *The condition under which the placed reflector can successfully launch an attack on the target sensor is*

$$\frac{3\lambda}{4} < d_{MC,R} + d_{R,s_{target}} - d_{MC,s_{target}} < \lambda. \tag{4}$$

PROOF. According to principle of wave interference, when the phase difference between the direct wave and the reflected wave meets the following condition, they will destructively interfere:

$$\frac{3\pi}{2} < \frac{2\pi}{\lambda}(d_{MC,R} + d_{R,s_{target}} - d_{MC,s_{target}}) < 2\pi. \tag{5}$$

Apparently, this means that when the path difference between the two waves satisfies $\frac{3\lambda}{4} < d_{MC,R} + d_{R,s_{target}} - d_{MC,s_{target}} < \lambda$, destructive interference will occur. Hence, the theorem is proven. □