A. ONLINE APPENDIX FOR ECONOMICS OF SEMANTIC COMMUNICATION SYSTEM IN WIRELESS POWERED INTERNET OF THINGS

The deep learning based auction consists of three major functions: monotone increasing function, $\Phi_n(\cdot)$, allocation rule, $z_n(\cdot)$, and conditional payment rule, $\theta_n(\cdot)$. Firstly, the input bids, b_n, $n = 1, \ldots, N$, will be transformed by Q groups of S linear functions, followed by the $\min$ and $\max$ operations, i.e., the transformed bid,

$$\overline{b}_n = \Phi_n(b_n) = \min_{q \in Q} \max_{s \in S} (w_{qs}^n b_n + \beta_{qs}^n), \tag{4}$$

where $w_{qs}^n \in \mathbb{R}_+$, $q = 1, \ldots, Q$, $j = 1, \ldots, J$ and $\beta_{qs}^n \in \mathbb{R}$, $q = 1, \ldots, Q$, $j = 1, \ldots, J$ are the weight and bias to be trained, respectively. The linear functions are strictly monotonically increasing functions to ensure the properties of IC and IR of the auction:

Theorem 1. *For any set of strictly monotonically increasing function $\{\Phi_1, \ldots, \Phi_N\}$, an auction defined by allocation rule $z_n = z_n^0 \circ \Phi_n$ and the payment rule $\theta_n = \Phi_n^{-1} \circ \theta_n^0 \circ \Phi_n$ is IC and IR, where z^0 and θ^0 are the allocation and payment rule of a second price auction with zero reserve.*

To ensure that the auction learned by the network is IC and IR, we constraint the allocation and payment rules of the network by following Theorem 1. After the monotone transformation, the transformed bids are passed to separate networks that approximate the allocation and payment rule. The allocation rule which follows the second price auction with zero reserve (SPA-0) allocation rule is approximated by a softmax function to maximize the allocation probability of the highest bid,

$$z_n(\overline{\mathbf{b}}) = \frac{e^{\kappa \overline{b}_n}}{\sum_{j=1}^{N+1} e^{\kappa \overline{b}_j}}, \tag{5}$$

where $\overline{\mathbf{b}} = (\overline{b}_1, \ldots, \overline{b}_{N+1})$, $\overline{b}_{N+1}$ is an additional dummy input, and κ determines the quality of the approximation. The higher the value of κ, the higher the accuracy of approximation but the allocation function will be less smooth and harder to optimize. The payment rule applies the inverse transformation function on the SPA-0 price of the transformed bids,

$$\theta_n(\overline{\mathbf{b}}) = \Phi_n^{-1}(ReLU\{\max_{j \neq n} \overline{b}_j\}), \tag{6}$$

where $ReLU(x) = \max(x, 0)$ is used to ensure that the payment is non-negative, and

$$\Phi_n^{-1}(y) = \max_{q \in Q} \min_{s \in S} (w_{qs}^n)^{-1}(y - \beta_{qs}^n). \tag{7}$$

To maximize the revenue, the network optimizes a loss function that is the negative value of the seller revenue. The loss function is given by

$$\hat{R}(\mathbf{w}, \boldsymbol{\beta}) = -\sum_{n=1}^{N} z_n(\overline{\mathbf{b}}) \theta_n(\overline{\mathbf{b}}). \tag{8}$$