A Privacy-Preserving Social-Aware Incentive System for Word-of-Mouth Advertisement Dissemination on Smart Mobile Devices

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Smartphones allow innovative advertising.

From the **direct** model (B2C)…
Smartphones allow innovative advertising.

...to the word-of-mouth model (C2C).
Word-of-mouth?

cost effectiveness + user intelligence

“..., send forth thy word, and let it fly.”

— Thomas Gibbons
Word-of-mouth?

cost effectiveness + user intelligence
Word-of-mouth?

cost effectiveness + user intelligence

Our friends know us better than strangers.
What is interesting for a computer scientist?

- **Incentive.**
  - Why shall a user care?
  - Align the interests of users and businesses.
  - Encourage users to invite their interested friends.
  - Encourage businesses by empowering them with control over budget.
  - No spamming, please.

- **Enforcement.**
  - Detect misbehavior.
  - No one takes blame for others’ wrongdoings.

- **Privacy.**
  - Do not inadvertently divulge relationship to strangers.
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Incentive tickets, aka *coupons*.

A user can **redeem** a coupon (when **paying** for a service/merchandise) or **duplicate** it.

<table>
<thead>
<tr>
<th>Content $T_C$</th>
<th>What is the coupon good for?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray width $W_C$</td>
<td>Duplication restriction.</td>
</tr>
<tr>
<td>Available slots $L_C$</td>
<td>Number of available slots.</td>
</tr>
<tr>
<td>Authentication slots</td>
<td>For authentication.</td>
</tr>
</tbody>
</table>

Assume a Public-key Infrastructure (PKI).
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$I$</td>
<td>The incentive authority.</td>
</tr>
<tr>
<td>$s$</td>
<td>A shop.</td>
</tr>
<tr>
<td>$u, v, w$</td>
<td>Users.</td>
</tr>
<tr>
<td>$p_u$</td>
<td>User $u$’s redemption probability.</td>
</tr>
<tr>
<td>$k_u$</td>
<td>The number of user $u$’s contacts.</td>
</tr>
<tr>
<td>$M$</td>
<td>A text segment.</td>
</tr>
<tr>
<td>$M_1</td>
<td>M_2$</td>
</tr>
<tr>
<td>$C_n$</td>
<td>Coupon cached by $n$.</td>
</tr>
<tr>
<td>$T_C$</td>
<td>Front-page section of coupon $C$.</td>
</tr>
<tr>
<td>$W_C$</td>
<td>Spray width of coupon $C$.</td>
</tr>
<tr>
<td>$L_C$</td>
<td>Available slots of coupon $C$.</td>
</tr>
<tr>
<td>$K_n^+ / K_n^-$</td>
<td>$n$’s public/private key.</td>
</tr>
<tr>
<td>${M}_{K_n^-}$</td>
<td>$n$’s digital signature on the hash of $M$.</td>
</tr>
<tr>
<td>$E_I(M)$</td>
<td>Encrypt $M$ with $I$’s public key.</td>
</tr>
<tr>
<td>$x_n$</td>
<td>A cryptographic nonce generated by $n$.</td>
</tr>
<tr>
<td>$R_C$</td>
<td>Reward amount for coupon $C$.</td>
</tr>
<tr>
<td>$i_1, i_2, \cdots, i_l$</td>
<td>Identifiers in coupon circulation chain.</td>
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A coupon’s life cycle.

1. Shop $s$ requests a coupon from authority $I$. 

\[ s \rightarrow I : \ T_C, W_C, L_C \]
A coupon’s life cycle.

2. **Authority I issues** the coupon to shop $s$.

$$C_s = T_C, W_C | \langle L_C - 1 \rangle, E_I(\{T_C | W_C | L_C | s \}_{K_I} | x_s | I | s \).$$
A coupon’s life cycle.

3. Shop $s$ offers the coupon to user $u$.

$$C_u = T_C, W_C |(L_C - 2),$$

$$E_I(\{C_s | u\}_K^{-} | x_u | s | u)$$

$$| E_I(\{T_C | W_C | L_C | s\}_K^{-} | x_s | I | s).$$
A coupon’s life cycle.

4. User $u$ duplicates the coupon to user $v$.

$$C_v = T_C, W_C | (L_C - 3),$$

$$E_I(\{C_u \mid v\}_{K_u}^{-} | x_v \mid u \mid v)$$

$$| E_I(\{C_s \mid u\}_{K_s}^{-} | x_u \mid s \mid u)$$

$$| E_I(\{T_C \mid W_C \mid L_C \mid s\}_{K_I}^{-} | x_s \mid I \mid s).$$
A coupon’s life cycle.

5. User $v$ redeems the coupon at shop $s$.

$$v \rightarrow s : C_v$$
Prior-redemption verification.

Authority $I$ iteratively decrypts each slot and reconstructs the coupon’s circulation chain starting from the shop $s$. 
Protocol-compliant behaviors.

- Verify before accepting.
  - Signing transfers responsibility.
  - Never over-duplicate.
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What if...?
Tampering.

- \( \cdots \rightarrow u \rightarrow v \rightarrow w \rightarrow \cdots \).
- \( u \) and \( w \) are honest. \( v \) is malicious and tampers with the coupon.
- \( u \)'s signature protects \( u \) from being framed by \( u \).
- \( v \)'s signature holds \( v \) responsible for tampering.
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What if...?
Collusion.

► ⋯ → u → v → ⋯.

► v is honest. u is malicious, tampers with the coupon, and colludes with w by having w sign the tampered coupon.
► v will not notice.
► u will not be detected for misbehavior in verification...
► ... but w will be.
► Nobody wants to be scapegoat: w will not vouch for u.
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- Abiding by the protocol is in each user’s best interest.
- The circulation chain reconstructed from a redeemed incentive ticket faithfully reflects the incentive ticket’s circulation among users.
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Incentive.

- **Where** are the rewards from?
- **Who** should be rewarded?
- **How** should the rewards be dispensed?
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Where?

From the shop’s profits in sales where a coupon is redeemed: Shop $s$ tells authority $I$ the reward upper limit $R_C$.

- Only reward effective advertisement.
- Budget control: think about real-world coupon ("duplication not not valid").
Who?

\[ s = i_1 \rightarrow i_2 \rightarrow \cdots \rightarrow i_l \ (l \leq L_C) \]

\(i_2, \cdots, i_{l-1}\) are rewarded for their effort of duplicating.
How?

- **Uniform.**
  - Everybody receives the **same**.
  - Disadvantage: **diminished attractiveness** and **looping strategy**.

- **Geometric.**
  - $p$: sharing ratio between consecutive users $(0 < p < 1)$.
  - $p \approx 1$: degenerate to **uniform**.
  - $p \approx 0$: degenerate to **single-level** scheme; under-use user intelligence.

- **Social-aware.**
  - Insight: Reward level should be **fixed** and as **few** as **full** user-intelligence utilization allows.
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  - $i_1 \rightarrow i_2 \rightarrow \cdots \rightarrow i_l$ $(l \geq 2)$.
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  - $l \geq 4$: $i_{l-1}$ gets $\frac{1}{1+\alpha} R_C$; $i_{l-2}$ gets $\frac{\alpha}{1+\alpha} R_C$. $l = 3$: $i_{l-1}$ gets $\frac{1}{1+\alpha} R_C$. $l = 2$: no rewards.
How?

- **Uniform.**
  - Everybody receives the same.
  - Disadvantage: diminished attractiveness and looping strategy.

- **Geometric.**
  - $p$: sharing ratio between consecutive users $(0 < p < 1)$.
  - $p \approx 1$: degenerate to uniform.
  - $p \approx 0$: degenerate to single-level scheme; under-use user intelligence.

- **Social-aware.**
  - Insight: Reward level should be fixed and as few as full user-intelligence utilization allows.
  - Privacy mandates the level to be 2.
  - $i_1 \rightarrow i_2 \rightarrow \cdots \rightarrow i_l$ $(l \geq 2)$.
  - $l \geq 4$: $i_{l-1}$ gets $\frac{1}{1+\alpha} R_C$; $i_{l-2}$ gets $\frac{\alpha}{1+\alpha} R_C$. $l = 3$: $i_{l-1}$ gets $\frac{1}{1+\alpha} R_C$. $l = 2$: no rewards.
  - $\alpha$: social weight.
Adam Smith’s invisible hand metaphor.

If users and the shop share the same estimation about redemption probability distribution in the population, a social weight $\alpha = 1$ will lead to a desirable situation in which a user, acting on his own interest, serves the shop’s interest best.
Questions?
Thank you for your attention!