Solution for HW4

1 Problem 1

The protocol differs from that presented in class in that the user's identity is divided into $n+1$ pieces rather than 2 pieces, and the spending and deposit protocols are modified accordingly:

$$ID = ID_1 \oplus ID_2 \oplus \cdots \oplus ID_{n+1}$$

As long as the user doesn't overspend, her anonymity is obviously preserved. If she spends the coins $n+1$ times (or more), her identity should be exposed with probability $1-\epsilon$. The main difficulty was to determine the number of times k that the user's identity should be split into $n+1$ pieces to ensure that probability of $1-\epsilon$. In the original scheme, k was fixed: $k = 100$. Now, we want to determine k as a function of n and ϵ.

If the user spends the coin $n+1$ times, the bank knows $n+1$ values chosen uniformly independently at random from the set $\{ID_j\}$. The probability that these $n+1$ values are all distinct is:

$$p = \frac{\text{choices of (n+1) distinct values}}{\text{all choices of (n+1) values}} = \frac{(n+1)!}{(n+1)^{n+1}}$$

If we repeat this k times, the probability that the $n+1$ values are *never* distinct is $\epsilon = (1-p)^k$ and thus

$$k = \frac{\log \epsilon}{\log(1-p)}$$

If we replace the value for p in this equation and simplify with Stirling's formula for approximating factorials , we get:

$$k \approx -e^{n+1} \log \epsilon$$

This shows that k grows exponentially with n. While our solution works well for small values of n, it is not very scalable.

2 Problem 2

Part a:

The equation says that after revoking t pirated CD players, every player that was not revoked has at least one key not known to the revoked players. This key can be used to encrypt future content.

Part b:
Start with a set of n keys and give each player a different subset of these keys of size $n/2$ (assume n even). It is easy to verify that this family of subsets satisfies the condition of 2a for $t = 1$. Indeed, a subset of $n/2$ keys can never be fully contained within a different subset of the same size. The number of players we can support is:

$$m = \binom{n}{n/2} = \frac{n!}{(n/2)!(n/2)!}$$

Stirling's approximation for factorials gives:

$$n! \approx \sqrt{2\pi n}(n/e)^n$$

This allows us to simplify the formula for m:

$$m \approx 2^n \sqrt{\frac{2}{\pi n}}$$

And thus $\log m \approx n - 1/2 \log n$ which shows $n = O(\log m)$.

Part c:
Start with a set of n^2 keys indexed by (i, j) for $1 \leq i, j \leq n$. Pick for each player a different subset S of the integers in the range $[1; n]$ such that the subset S is of size $n/2$. Give each player all the keys (i, j) for which $i \in S$ and $j \in S$.

It is easy to convince yourself that the family of sets thus defined satisfies the condition of 2a for $t = 2$. Suppose users A and B have been revoked. Consider user C. Since $S_A \neq S_C$, there is at least an index i which belongs to S_C but not to S_A. Similarly, there exists an index j which belongs to S_C but not to S_B. The key (i, j) is known to C, but not to A or B.

The number of players supported by this scheme is as in 2b. Therefore $n = O(\log m)$ and the total number of keys is $n^2 = O(\log^2 m)$.