Call Algebra

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Abstract

In every day life, people communicate through a voice(e.g., VoIP) network with different social groups that range from known people such as family members, friends, and distant relatives to unknown people such as spammers, telemarketers, and phishers. We believe that there exists a human/social dynamics between individuals by the way calls are generated, handled and received. In this paper we present how this dynamics can be used for detecting and filtering unwanted calls. In this paper, we first enumerate the communication patterns between the called party (callee) and the calling parties (callers). Next, we discuss operations on caller-callee matrices constructed based on their communication patterns, and derive call-constructs that can be used for determining the legitimacy of the calls and the callers. Finally, we discuss how these communication patterns and operations can be grouped for solutions to few of the existing IP telephony problems. These solutions can complement the existing *no-call-lists* in voice networks.

1. Introduction

People communicate on the VoIP network with different groups of individuals such as family members, friends, and relatives. Occasionally, people also receive unwanted calls from unknown callers such as strangers and spammers. These unwanted calls create nuisance and inconvenience to the end callee. In addition to spam calls from unknown people, there can be unwanted calls from legitimate callers too. In this case, the unwantedness is based on the callee's present context. For example, a corporate executive might resent unnecessary calls from close people such as family members and friends when he is at office, and prefers only from close people during non-work hours. Therefore, it is necessary that quarantining techniques not only include models for learning caller behavior, but also integrate the tolerance and presence (mood or state of mind) based on present context (spatial, situational, and temporal) of the callees.

While research about filtering spam calls exists in the present literature, to our knowledge, there is no work reported on the formal analysis of the call dynamics that exist between humans on a VoIP network. Rosenberg et al [1] discussed the problem of VoIP spam calls in IP networks. Rebahi et al [2] presented a spam filtering technique based on recommendations from social network elements and suggested deriving reputation of the source of the call. Macintosh et al [3] presented a filtering technique that uses deviation from normal call distribution using statistical analysis. Shin et al [4] discussed a spam filtering technique using rate of incoming VoIP calls. Kolan et al [5] discussed a VoIP spam detection framework that involves trust and reputation computation using direct experiences and peer recommendations. Kolan et al [6] presented a nuisance detection framework that pro-actively infers the callee's eagerness in receiving incoming voice calls.

Based on survey of recent research and our own work, we believe that a human-social dynamics exists in the ways humans make and receive calls with individuals. This dynamics depends on the relationship between the individuals. We believe that this human/social dynamics can be used for providing solutions for multitude of problems related to identification of wanted calls and solicited callers.

2. Methodology

A social and human dynamics exists in the way callers and callees exchange real-time voice calls. This dynamics, of course, differs depending on the type of person the callees are communicating with at any specific time on the voice network. For example, the callees spend considerable time communicating with family members, friends, and distant relatives, but have an insignificant amount of communication with strangers such as telemarketers and fund-raisers. However, within this broad range of activity, we can draw some general conclusions about the types of calls that occur. In Section 2.1, we present the dynamics by enumerating algebraic rules that represent communication patterns among individuals. In Section 2.2, we discuss how the patterns can be used to derive meaningful call-constructs that help in identifying the legitimacy of calls. In Section 2.3, we discuss how the communication patterns and call-constructs can be used for providing solutions to IP telephony problems.

2.1 Algebraic rules

We can divide the individuals communicating with a callee into four broad categories [6].

1. Socially Close Members - These are the people with whom the callee maintains the highest connectivity on the communication network e.g., family members, friends, and colleagues
2. Socially Near Members - People in this category are not as highly connected as socially close members, but when the callee connects to them, the callee talks to them for considerably longer periods e.g., neighbors and distant relatives.

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3. Opt-ins - These individuals have less connection with the callee's social life. The callee acknowledges the calls from these individuals rarely e.g., discussion groups and newsletters.

4. Opt-outs - These people are least connected with the callee on the communication network e.g., strangers, telemarketers, fund raisers.

For each type, we derived algebraic relations that describe the communication the type's callers have with a callee or the callee's community members. We enumerated the communication patterns for such relationships as associative, distributive, and commutative. Consider a community with m members, and each member having a maximum of n number of people in each of the four types we have defined before. The people communicating with a callee R_i for i=1..m are represented by S_{ijk} (caller k belonging to group number j of community member R_i for i=1..m, j=1..4 and k=1..n).

(1). *Calls from Socially Close and socially near members are distributive*

Whenever, a socially close or socially near member intends to communicate with the callee or the callee's community, the caller can create a conference or call each community member to communicate individually. In either case, the callee will have similar willingness/interest for completing the call. Therefore, we have $S_{ijk} \rightarrow (R_1, R_2, ...,R_l) = (S_{ijk} \rightarrow R_1)$ U $(S_{ijk} \rightarrow R_2)$ U .... $(S_{ijk} \rightarrow R_l)$ for $i,l \in 1..m, j \in 1..2, k \in 1..n$ i.e. the calls are distributive with respect to socially close and socially near members.

(2). *Calls from socially close and socially near members are commutative*

There is always a mutual interest in call-generation and reception between a callee and socially close and socially near members, i.e., the members make calls to the callee and the callee returns calls to them. We can show this commutative relation as follows

$S_{ijk} \rightarrow R_l = R_l \rightarrow S_{ijk}$ for $i,l \in 1..m, j \in 1..2, k \in 1..n$

(3). *Calls from socially close and socially near members are associative.*

When a socially close or socially near member intends to communicate with two callees, the member can (a) make a call to a callee, and then invite another callee $[(S_{ijk} \rightarrow R_l) \rightarrow R_s$ for $i,l,s \in 1..m, j \in 1..2, k \in 1..n]$, or, can join an already progressing conference between two callees $[S_{ijk} \rightarrow (R_l \rightarrow R_s)$ for $i,l,s \in 1..m, j \in 1..2, k \in 1..n]$. In either way, the willingness/interest of all the three participants will be same. Therefore, we have $(S_{ijk} \rightarrow R_l) \rightarrow R_s = S_{ijk} \rightarrow (R_l \rightarrow R_s)$ for $i,l,s \in 1..m, j \in 1..2, k \in 1..n$ i.e., the calls are associative.

(4) *Calls from opt-ins are limited commutative, not distributive.*

Opt-ins are callers from whom a callee may occasionally solicit information. At the time of the solicitation, the callee considers the calls from opt-ins reasonable and may acknowledge the calls i.e. they bear a limited commutative relationship $[S_{i3k} \rightarrow R_l = R_l \xrightarrow{l} S_{i3k}$ for $i,l \in 1..m, k \in 1..n]$. Depending on the callee who has acknowledged, the opt-ins make calls to them individually. All calls from the opt-ins to each callee are simple one-to-one calls and therefore, not distributive.

(5) *Calls from opt-outs are not commutative, but are distributive*

Callees do not want to receive calls from opt-outs. Virtually no one calls back opt-outs. Therefore, this communication is never commutative. When an opt-out caller intends to communicate with all the members of a callee's community, the caller generates a conference call. This can be described as $[S_{i4k} \rightarrow (R_1, R_2, ...,R_m)]$. Alternatively, the opt-out caller can make a unicast call to each callee i.e., $[S_{i4k} \rightarrow (R_l)$ for $i,l \in 1..m, k \in 1..n]$. Therefore, $S_{i4k} \rightarrow (R_1, R_2, ...,R_m) = (S_{i4k} \rightarrow R_1)$ U $(S_{i4k} \rightarrow R_2)$ U .... $(S_{i4k} \rightarrow R_m)$ for $i,l \in 1..m, k \in 1..n$ i.e., the calls are distributive.

(6) *Calls from opt-ins and opt-outs are not associative*

It is rarely observed that the callees acknowledge multicast calls from callers belonging to the opt-in and opt-out group. No opt-ins or opt-outs would organize or join conferences. Therefore, calls from opt-ins and opt-outs are not associative.

All the above rules describe the calling patterns callees have with their social network members. We can analyze these calling patterns with some operations to generate meaningful call-constructs that can be used to provide solutions to a number of telephony problems.

2.2. Operations based on calling patterns

Current research problems in telephony applications deal with identifying the legitimacy of the incoming calls and the callers making those calls. In this section, we describe operations on the caller-callee calling patterns that provide filtering characteristics for identifying the legitimacy of incoming calls and the callers making those calls.

Few fundamental parameters that we can extract based on communication between a caller and a callee are frequency, duration, time-of-arrival, and inter-arrival time. Based on these communication parameters, we can define caller-callee matrices that describe the communication between multiple callers and callees. For m callees (R_i for i = 1..m) inside the callee's

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community and p callers ($\{S_l\}_{l=1..p} = \{S_{ijk}\}_{i=1..m,\ j=1..4,\ k=1..n}$ i.e., all callers to all callees) making calls to the callees in the community, a matrix for parameter K(e.g., frequency, duration, time of arrival, and inter-arrival time) based on the communication between the callers and the callees can be shown as

$$SR_K = \begin{array}{c} \\ S_1 \\ S_2 \\ . \\ . \\ . \\ . \\ S_p \end{array} \begin{array}{c} \begin{array}{cccccc} R_1 & R_2 & . & . & . & R_m \end{array} \\ \begin{bmatrix} (S_1R_1)_K & (S_1R_2)_K & . & . & . & (S_1R_m)_K \\ (S_2R_1)_K & (S_2R_2)_K & . & . & . & (S_2R_m)_K \\ . & & & & & \\ . & & & & & \\ . & & & & & \\ . & & & & & \\ (S_pR_1)_K & (S_pR_2)_K & . & . & . & (S_pR_m)_K \end{bmatrix} \end{array}$$

Based on the above representation, we can construct parameter matrices such as frequency (SR_F), duration (SR_D), time of arrival (SR_T), and inter-arrival time (SR_I). However, callees also generate calls to callers (outgoing calls). So, we could define outgoing matrices such as RS_F, RS_D, RS_T, *and* RS_I. Using these incoming and outgoing matrices, we discuss some operations for deriving call constructs.

2.2.1. Connectivity

Connectivity represents the amount of communication the parties have in a voice network. This amount of communication can be measured based on the extent of frequency and duration of calls between the parties. We argue that higher the connectivity, higher will be the trust between the caller and the callee.

2.2.1.1 Connectivity based on incoming calls: The matrices SR_F and SR_D can be used for determining the connectivity of the callers to the callees based on incoming calls. For example, consider multiplying the frequency and the transpose of the duration matrix. The result is a matrix C^S where each element is given by

$$C^S_{ij}=(S_iR_1)_F*(S_jR_1)_D+(S_iR_2)_F*(S_jR_2)_D+...+(S_pR_m)_F*(S_jR_m)_D=\sum_{k=1}^{m}(S_iR_k)_F*(S_jR_k)_D$$

for i, jЄ 1..p. Diagonal element (C^S_{ij} such that i=j for i, jЄ 1..p) represents the connectivity of caller S_i with respect to all callees for iЄ 1..p. We can infer that, higher the value of the diagonal element, higher is the connectivity of respective caller towards all the callees.

2.2.1.2 Connectivity based on outgoing calls: Similar to the operation shown for incoming calls, we can use the outgoing call matrices RS_F and RS_D to establish the connectivity of callees.

While connectivity gives information about the direct trust based on past communication, we can derive more legitimacy information based on forwarded calls.

2.2.2 Reputation:

Reputation represents social status. It is derived based on recommendations from trusted peers[5]. However, with respect to calling patterns, we believe that the reputation can be derived based on the preference (addressed using call forwarding) of calls from the callers and the callees.

2.2.2.1 Reputation based on incoming calls: The reputation of the callers can be derived using the multiplication operation between the SR_F and RS_F matrices

Consider a matrix D^R defined to be equal to SR_F * RS_F. Each element of the matrix D^R is defined by

$$D^R_{ij} = S_iR_1 * R_1S_j + S_iR_2 * R_2S_j + ... + S_iR_m * R_mS_j = \sum_{k=1}^{m} S_iR_k * R_kS_j$$

From the above equation, we can assume that for a call from a caller S_i to a callee R_k for kЄ 1..m, the callee forwards the call to another caller S_j for i, jЄ 1..p. We believe this is call-forward function represents the reputation of the caller. Therefore, D^R_{ij} of matrix D^R gives the reputation of caller S_i for i,jЄ 1..p & $i \neq j$.

2.2.2.2 Reputation based on outgoing calls:

We can derive reputation of callees using the same RS_F and SR_F matrices by performing the multiplication operation RS_F * SR_F. The result of this multiplication operation is a matrix D^S. Each element of the matrix D^S can be represented as $D^S_{ij} = \sum_{k=1}^{p} R_iS_k * S_kR_j$. Each non-diagonal element of the matrix D^S (D^S_{ij} such that $i \neq j$ for i, jЄ 1..m) represents the call-forward function for all calls from R_i to R_j by S_k i.e., D^S_{ij} represents the reputation of R_i for i,j Є 1..m & k Є 1..p.

The connectivity and reputation information provides a measure of legitimacy of calls. In addition to these measures, we can also derive functions for parameters such as reciprocity and periodicity.

2.2.3 Reciprocity

Reciprocity represents the response shown by one party to calls from another party(e.g., returning back a missed call). This reciprocity can be established using the SR_F and RS_F matrices.

2.2.3.1 Reciprocity based on incoming calls

The reciprocity shown by callees can be determined using a multiplication operation between the SR_F and RS_F matrices. For the matrix D^R = SR_F * RS_F shown in 2.2.2.1, each element of the matrix is represented by $D^R_{ij} = S_iR_1 * R_1S_j + S_iR_2 * R_2S_j + ... + S_iR_m * R_mS_j$ i.e., $D^R_{ij} = \sum_{k=1}^{m} S_iR_k * R_kS_j$. In matrix D^R, the diagonal elements are of the form $D^R_{ij} = \sum_{k=1}^{m} S_iR_k * R_kS_i$ for i Є 1..p (since i=j). We note that when we extract the diagonal

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elements, the i^{th} diagonal element represents the call-back function to the caller S_i, i.e., the i^{th} diagonal element represents the reciprocity shown by callees to calls from the caller S_i for $i \in 1..p$.

2.2.3.2 Reciprocity based on outgoing calls: Similar to the derivation shown for reciprocity shown by callees, each diagonal element D^S_{ij} of matrix $D^S = RS_F * SR_F$ gives the reciprocity shown by callers to calls from callees.

Although the parties show eagerness to return the unanswered calls, they often tend to acknowledge calls mostly during some defined intervals. These intervals can be described by computing periodicity of the incoming or outgoing calls.

2.2.4 Periodicity:

It is of common observation that people prefer defined intervals for communicating with other parties (e.g., after-work hours. Periodicity represents the regularity in which the callees accept/make calls from/to the callers. One way of defining a periodicity matrix is as follows: Define matrix M such that each element in the matrix is defined by M_{ijk} = Number of calls received by callee j from caller i at time unit k for $i \in 1..p$, $j \in 1..m$, $k \in 1..nt$, where nt is the number of time intervals. Using matrix M, we can derive a periodicity matrix P^t such that each element $P^t_{i,j}$ represents the periodicity of calls from caller S_i to callee R_j for $i \in 1..p$, $j \in 1..m$ at time interval t and is defined as follows:

$$P^t_{i,j} = \frac{M_{ijt}}{\sum_{k=1}^{nt} M_{ijk}}$$

We can use the matrix operations defined in this section with the algebraic rules (Section 2.1) for solving important problems such as detecting spam and botnets.

2.3. Applications

One of the important problems in IP telephony research is the task of identifying unwanted calls. In this section, we discuss some research problems related to identifying unwanted calls, and derive solutions to those problems using the rules and operations we have discussed before.

2.3.1. Spam Filtering:

Incoming calls from spammers and phishers are considered to be spam and are unwanted to the callee. Here we present steps for designing a real-time spam filtering application that filters unwanted spam calls. *The procedure outlined here is an example, but a detailed solution can be found in [5].*

(a) Determine callers'/callees' connectivity using communication patterns (Section 2.2.1).

(b) Define a trust matrix F such that each element F_{ij} represents the perceived trust (connectivity) of caller S_i by callee R_j for $i \in 1..p$ & $j \in 1..m$.

(c) Define a reputation matrix Y such that each element Y_{ij} represents the reputation of caller S_i with respect to callee R_j for $i \in 1..p$ & $j \in 1..m$ (Section 2.2.2).

(d) Define a spam probability matrix L such that each element L_{ij} represents the probability of caller S_i to be perceived as spam by callee R_j for $i \in 1..p$ & $j \in 1..m$. One way of computing spam probability is using a correlation function between the trust and reputation: $L_{ij} = 1-(\alpha_F * F_{ij} + (1-\alpha_F)Y_{ij})$ where α_F is defined by callee.

2.3.2.* Defining *Social Groups:

We enumerate steps for classifying callers into four social groups as defined in Section 2. *The procedure outlined here is an example, but a detailed solution can be found in [6]*

(a) Derive closeness of each caller to the callee based on the incoming calls. Construct a matrix G^I such that each element $G^I_{ij} = \sqrt{(S_iR_j)_F{}^2 + (S_iR_j)_D{}^2}$ represents the closeness of caller S_i to callee R_j for $i \in 1..p$ & $j \in 1..m$. Similarly, derive closeness of each caller to the callee based on outgoing calls. For deriving this closeness, construct matrix G^O such that each element $G^O_{ij} = \sqrt{(R_iS_j)_F{}^2 + (R_iS_j)_D{}^2}$. Each element G^O_{ij} represents the closeness of callee R_i to caller S_j for $i \in 1..m$ & $j \in 1..p$.

(b) A caller's closeness to a callee depends on the closeness based on incoming and outgoing calls from and to the callee. This dependency can be a simple correlation function such as α_G (Closeness based on incoming calls) + $(1-\alpha_G)$(Closeness based on outgoing calls) where α_G is defined by the callee.

(c) Define closeness thresholds (e.g., 0.9-1.0: socially close, 0.7-0.9: socially near, 0.5-0.7: opt-in, 0-0.5: opt-out.) for categorizing callers.

2.3.3. Nuisance Computation:

Every real-time call is associated with certain amount of nuisance. This nuisance is less for calls from close people compared to unknown callers. The nuisance for an incoming voice call can be computed as follows (*procedure outlined here is an example, but a detailed solution can be found in [6]*)

(a) Define a matrix W for representing callees' eagerness in receiving calls. Each element W_{ij} represents the callee R_j's eagerness(e.g., derived from

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connectivity) in receiving calls from caller S_i for $i€$ 1..p & $j€$ 1..m.

(b) Define a reciprocity matrix D^R such that each element D^R_{ij} represents the reciprocity shown by callee R_j for calls from caller S_i for $i€1..p$ & $j€1..m$ (Section 2.2.3).

(c) Define a Periodicity matrix P such that each element P_{ijk} represents the periodicity of calls from caller S_i to callee R_j at time interval k for $i€1..p, j€1..m, k€1..nt$.

(d) Define a nuisance matrix N such that each element N_{ij} (e.g., $N_{ij} = \frac{1}{W_{ij} + D^R_{ij} + P_{ij}}$) represents the nuisance for callee R_j because of calls from caller S_i for $i€1..p$ & $j€1..m$.

2.3.4. Botnets identification:

Botnet is a term used for collection of compromised systems (known as "bots") that are used as a starting point for generating attacks. We can design an application that identifies bots using time series analysis. *The procedure outlined here is an example, but a detailed solution can be found in [8].*

(a) Define a matrix B which records the communication parameters for the calls originating from all the hosts (used by the callers to generate calls). Each element of matrix B (i.e., B_{ij}) represents the normalized value of communication parameter(such as frequency, duration) j for $j€1..np$ (np is the number of parameters) of host i for $i€1..q$.

(b) Derive Eigen values of matrix B. Define a set of Eigen vectors $[e'_1, e'_2, ..., e'_k]$ i.e., the first k prominent Eigen vectors that describe the data values in matrix B [10].

(c) Compute the correlation matrix based on the Eigen matrix. Each element X_{ij} represents the correlation (e.g., Pearson's correlation coefficient[7]) of host i with host j for $i€1..q, j€1..k$.

(d) Using correlation values in matrix X, we can use clustering techniques such as K-means, Fuzzy C-means, and Hierarchical clustering for grouping hosts into clusters to classify botnets [10].

3. Conclusion

Unwanted voice calls in a communication network such as PSTN, cellular, or IP cause nuisance and inconvenience to the callee. In this paper, we discussed human/social dynamics that exist between individuals in the way they make and receive calls. The dynamics incorporates rules for normal communication behavior between individuals and the people they communicate such as family members, friends, and distant relatives. Using the defined rules and communication patterns, we derived call-constructs for determining the legitimacy of incoming calls and callers making those calls. In the end we discussed how the communication patterns and the operations for call-constructs can be grouped to result in solutions for existing telephony problems. We believe that the existing filtering techniques can integrate these rules and operations for improving the filter accuracy. Although we discussed the dynamics in context of communication in VoIP networks, the presented solutions can be applied to different voice networks such as PSTN and Cellular.

References

1. J. Rosenberg, C. Jennings, AND J. Peterson, "The Session Initiation Protocol (SIP) and Spam", Spam Draft - draft-ietf-sipping-spam-02.txt, 2006
2. Y. Rebahi AND D. Sisalem, "SIP Service Providers and the Spam Problem", Proceedings of Voice over IP Security Workshop, Washington, USA, 2005
3. R. Macintosh AND D. Vinokurov, "Detection and Mitigation of Spam in IP Telephony Networks using Signaling Protocol Analysis", In Proceedings of IEEE symposium on Advances in Wired and Wireless Communication, Page(s):49 - 52, 2005.
4. D. Shin AND C. Shim, "Voice Spam Control with Gray Leveling", In Proceedings of 2nd VoIP Security Workshop, Washington DC, 2005
5. P. Kolan AND R. Dantu, "Socio-Technical Defense against Voice Spamming", ACM Transactions on Autonomous and Adaptive Systems (TAAS), March 2007
6. P. Kolan AND R. Dantu, "Nuisance Level of a Voice Call", ACM Transactions on Multimedia Computing, Communications, and Applications, Oct 2007
7. Correlation Coefficient, http://mathworld.wolfram.com/CorrelationCoefficient.html
8. S. Palla, H. Husna, R. Dantu, AND J.W. Cangussu, "Behavior Patterns of Spam Botnets," Conference on Email and Anti-Spam (CEAS),2007
9. C. E. Shannon, "A Mathematical Theory of Communication," Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October 1948
10. S.Palla,"A Multi-Variate Analysis of SMTP Paths and Relays to Restrict Spam and Phishing Attacks in Emails," Masters Thesis, University of North Texas, Dec 2006

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