

Tie Strength in Online Social Networks and its Applications: A Brief Study

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Abstract

In online social network (OSN), understanding the factors bound to the role and strength of interaction(tie) are essential to model a wide variety of network-based applications. The recognition of these interactions can enhance the accuracy of link prediction, improve in ranking of dominants, reliability of recommendation and enhance targeted marketing as decision support system. In recent years, research interest on tie strength measures in OSN and its applications to diverse areas have increased, therefore it needs a comprehensive review covering tie strength estimation systematically. The objective of this paper is to provide an in-depth review, analyze and explore the tie strength in online social networks. A methodical category for tie strength estimation techniques are discussed and analyzed in a wide variety of network types. Representative applications of tie strength estimation are also addressed. Finally, a set of future challenges of the tie strength in online social networks is discussed.

1 Introduction

A social network is a social organization of social actors and interactions among these actors as its integral parts. With the surge of information technology and online social networks (OSN) platforms such as Facebook, Instagram, Twitter, LinkedIn, YouTube, Snapchat, Pinterest and ibo [43]; the collaboration between people have taken new dimensions and rise of online social networks. Meanwhile, splendid developments in mobile communication and wireless technology have improved the operations and services used by OSN, this resulted into emergence of another genre of social network called mobile social network (MSN). Essentially, MSN or OSN, have unique features where individuals with commonalities and alike interests can possibly connect people with one another. Social networks in these social context can be mapped into graphs, where nodes stand for
individuals and the edges layout the relationships among them. The characteristics and features from the graph and other metrics related to such networks can be utilized to study the behavior of individual. Finally, such networks can leverage to define many interesting applications including link prediction, recommendation system, ranking groups and individuals, pattern analysis and information diffusion [18, 28, 20]. The interactions and relationships among network structure can offer access to target information effectively. Knowledge of the strength of these relationships; furthermore the social dynamics provide new insights and shown to enhance correctness of link prediction, reliability of recommendation for collaboration, improve ranking for influence and fraud detection [1, 39], make better model for information and disease spread and lead to enhance targeted marketing as decision support system. The property of relationship/tie strength ascertains to investigate and measure the interaction based on the knowledge extracted from the graph, social context, communication patterns and other related features. In the recent years, research interest on tie strength measure in online social networks and its applications to various areas has increased. Fig 1 shows the importance of area field observed in terms of the number of published papers from three important digital libraries of computer science from 2007 to 2018 with search keywords “tie strength online social networks”. The research trend on the problem of ties strength in online social networks has shown a rise during these years as increase in number of publications can be seen on this topic. In the light of this notable growth in area and to understand the wide variety factors related with tie strength, it is essential to cover the reviews study of the topic. This paper contributes an overview study of tie strength in online social networks and its applications to sort the solutions in various dimensions; including management science, business analytic, social science and computer science. First it gives the tie strength statement which includes formal definitions, types of ties and a generic framework for this metric. Then it presents strength estimation techniques from five major aspects such as; node based, communication pattern based, multimedia contents and learning based, geo-information based and temporal information based. It majorly describes typical approaches based on topological features and multimedia contents based machine learning approaches with tie strength applications. Finally, beside the current research, it outlines the future challenges for tie strength estimation. The rest of the paper is organized as follows. The problem statement and importance of tie strength is explained in section 2. Various techniques to estimate tie strength are classified and discussed in section 3. Section 4 covers range of applications of the tie strength metric. Sections 5 and 6 draw the future challenges and conclusion from this study.

2 Problem Statement

Consider a social network \((G, V)\), where \(V\) denotes the set of nodes and \(E\) denotes the set of links. The tie strength estimation aims to indicate the value ( nominal or discrete) of an edge between two nodes which has a spectrum of
widely accepted definitions. These ties in social networks have been categorized in the seminal work by Granovetter [13] as weak ties and strong ties based on: interaction time, level of intimacy, emotional intensity and reciprocity. The strong ties are functional in a variety of situations with close friends and family members. Similarly, weak ties have less intense relationship between nodes according to above factors. Other class of ties such as latent ties, dormant ties and intermediate ties have also been defined by authors. The tie strength notion according to Granovetter’s hypothesis (fig. 2) can be explained from schematic network of nodes with related features to define weak and strong ties.

2.1 Importance of strong ties and weak ties

The user in OSN can have weak or strong ties within the network, which maintains different levels of shared interest and belief system according to its strength. In the detailed work of its kind, Onnela et al. [28] studied the relation-
ship between tie strength and structure of mobile networks on phone logs data. Authors found that strong ties cover prime role in maintaining local subgroups, however weak ties appear to cover important part for maintaining the networks cohesive strength. Weak ties are also related to the Burt’s concept of structural hole \[8\] and Granovetter’s concept of local bridge \[13\] which play vital roles in providing novel information and information propagation on network. Strong ties are described to have strong control methods and tend to have trusted relationship which proved to target for network related decision support systems \[32\].

3 Tie strength estimation techniques

There are numerous fundamental approaches to estimate tie strength. The approaches mainly employ network topology, community, node and link level information. Approaches which look into the information related to social media data such as location and geographical information, co-location statistics, mobility behavior, communication patterns and temporal information, rely on the these platform and peer-to-peer communication patterns. Moreover, latent variables and learning based methods are more complex as authors incorporate additional external information for the estimation of this metric. This section tracks together a systematic review for the techniques of estimation of tie strength (fig. 3) in online social networks.

3.1 Node-based metrics

Computing the tie strength of a node pair based on nodes information is an intuitive solution. According to “the weak tie hypothesis” \[13\], local network structure around pair of nodes exhibits important correlation with tie strength
and relative overlap \(O_{xy}\) of common neighbors for nodes is defined as:

\[
O_{xy} = \frac{n_{xy}}{(k_x - 1) + (k_y + 1) - n_{xy}} \quad (1)
\]

Where \(x, y\) connected nodes pair have \(n_{xy}\) common neighbors and \(k_x, k_y\) are individual neighbors of nodes \(x, y\) respectively. Highly established node similarity indices such as path distance, number of common neighbors that two nodes share and proximity of nodes pair \([22, 48]\) are used to infer link weight and tie strength measures which have further application to the link prediction problem. Newman \([27]\) suggested a measure of tie strength of collaboration network which considers number of papers of two scientists in collaboration and number of coauthors for those collaborations as index of tie strength between them. Nowell and Kleinberg \([22]\) has reported a review of tie strength measures based on local proximity of node pairs. Brandão and Moro \([7]\) investigated co-authorship tie strength using common neighborhood overlap in the scholarly network. Node based metrics are basic and easy to incorporate as authors mainly use nodal information and actions, however additional attributes to this category leads to enhance accuracy of estimating this metric \([18]\).

### 3.2 Communication pattern-based metric

Online social networks provide IT-enabled communication environment, where social networks such as communities, society and organizations engage the individuals to communicate for the purposes and have certain interaction patterns. The communication in the forms of messages, emails and calls and all the contents of such interactions can be presented in terms of edge attributes. Therefore, analyzing the patterns of communication provides an interesting insight to estimate tie strength in such settings. Onnela et al.\([28]\) investigated tie strength metric by call duration and cumulative number of such calls between individuals along with its local topology in the mobile communication network. Pappalardo et al.\([29]\) explored a multidimensional network built over Facebook, Twitter and Foursquare to introduce tie strength estimation based on number on interactions of nodes. Other studies \([41, 24]\) have investigated accuracy of having communication patterns correlated to the tie strength. Furthermore, incorporating the contents information of communication links can improve the precision of this metric.

### 3.3 Geo information-based metrics

Development of web-based centralized applications and similarly functionality to mobile networks provide online social networks a deliverance of getting geographical. The evolution of geosocial networking \([14]\) allows user to communicate relative to their locations. Amazon, Facebook, Twitter, Google and eBay are among such platforms to include social APIs and expand geolocation technology. The study of online social networks in this dimension has acknowledged property of these networks in relation to geographical attributes.
of social media users along with their topological structure \cite{37}. The location data can be shared by users voluntarily or it can be based on geotagged contents such as tweets, flickr, Instagram or location based services like Foursquare check-ins. Geographical information provides additional features which is useful in applications such as location aware recommendation, marketing and sales analysis. Jeferrey et al. \cite{25} investigated the positive correlation between tie strength and distance between two users on twitter. Pharm et al. \cite{30} proposed an entropy-based model for estimating tie strength based on co-occurrence of individuals. Sadilek et al. \cite{34} conferred location prediction approach based on social tie strength. Authors combined location-based features along with topology of friendship graph information to determine the social tie strength. Further related studies \cite{14, 17} of measuring tie strength based on information such as distance between users, location and co-occurrence and their structural features, also confirm the positive dependency of the metric on location-based user information. The geolocating applications and emerging volume of users location-based data demonstrate an obvious threat to the privacy issue in this regard. However, efficient and reliable use of such information can be utilized for cutting-edge business applications.

3.4 Temporal information-based metrics

Static interpretations of online social networks usually fail to embrace temporal aspects of human activity. Social relationships vary with time and tend to show human actions as Markovian and randomly distributed events against time \cite{26}. The majority of OSNs show up this temporal pattern of changing edge sequences, varied intimacy of relations, emergence of new ties, time spans of communications, timelines of relationships and continuous changing activities over time. This temporal conduct of social networks can affect other factors applicable to tie strength determination in online social networks. In result, structural property (clustering coefficient, neighborhood overlap) and geographical property (community structure, distance, homophily) also receive conditional upshots \cite{26}. With increasing availability of massive temporal information of how people act and communicate, facilitate to include temporal property of OSN to accurately characterize underlying characteristics of tie strength estimation and dynamic process of such networks. Karsai et al. \cite{19} conferred amount and time of interaction to define link strength in large scale mobile phone network. Laurent et al. \cite{21} defined strong tie strength based on network structure of mobile communication and frequency of interactions among intra-community nodes. Brundo et al. \cite{6} identified tie strength in temporal network of co-authorship relations by measuring edge persistence and evolution of ties over time. To encode temporal network is a non-trivial task because it requires to maintain temporal ordering of edges and compute time with varying network properties. However, beyond this restraint of maintaining temporal features of OSN, tie strength estimation with temporal attributes could help in prominent applications such as co-authorship analysis and collaboration prediction, crime prediction in radically influenced networks \cite{21}, stock market fluctuation \cite{9}, also
3.5 Multimedia contents and learning-based tie strength

A cascade growth in online platforms of information system and social networking sites has shown a consequential surge in online content generation and sharing on such social networks. The contents generated by users include online comments on social networking sites such as Facebook and Twitter, sharing digital images (eg. on flickr), creating and working blogs, participating and posting on websites, creating tags, sharing ideas and sharing interests [42]. These contents are also called as linkage features or interaction contents of individuals, which provide schematic dimensions to the nodal attributes for a social network. The interaction contents of individuals on online social networks have been identified as strong factors for analyzing tie strength estimation [46, 40]. A model view of real-time update for online social networks and their tie strength estimation is represented in fig. 4. The multimedia contents of user profiles are provided by social media through their APIs, where users participate for various purposes such as media posting, messaging, business, health, hobbies, shopping and geotagging. The attributed graphs with node’s features vector are obtained from such user related contents. Further, applying various machine learning methods can determine the estimation of relationship strength on these attributed graphs. The learning methods for categorical node contents are provided further in this section.

Figure 4: Tie strength estimation model on online social networks with multimedia contents.
3.5.1 Multivariate features-based learning methods

Several recorded properties of online social networks play vital roles to understand various factors associated with tie strength estimation. Researchers have employed various methods of statistical machine learning for feature selection and prediction of key features for tie strength estimation [24, 10, 40, 12, 15]. Kanhanda et al. [18] exploited 50 transnational features of friendship network from multidimensional graph for relationship estimation based on Naive Bayesian classifier, logistic regression and bagged decision tree models. Giebert and Karahalios [12] presented multivariate static model, based on classes of user features to estimate tie strength on Facebook. Mattie et al. [24] used random forest regression and classification to predict tie strength based on categorical features from CDR call network. He et al. [16] employed multivariate step-wise regression to determine key features for tie strength estimation and verified model on Naive Bayesian classifier.

3.5.2 User activity based learning methods

The relationship strength among users in online networks varies in different activity fields therefore incorporating interaction activities with profile information can enumerate another dimension to relationship estimation. Zhao et al. [47] proposed a framework to measure tie strength on Facebook network incorporating interaction among users in activity fields on OSN. Xiong et al. [44] presented a model to measure tie strength between users in Sina network by considering similarity among profiles and interaction activity in various fields with co-occurrence of users. Authors used graphical model for the approach. Abufouda and Zweig [11] addressed link estimation on Facebook network, based on machine learning model on a set of associated interacting networks with Facebook’s friends network.

3.5.3 Supervised and semi-supervised learning models

There is a wide spectrum of learning based link strength estimation models due to high variability in node features and data availability. Tang et al. [36] proposed tie strength prediction task for partially labeled network data of mobile, email and publication networks. Authors proposed an algorithm to learn model parameters and to predict unknown relationships in a semi-supervised framework. Rotabi et al. [33] presented a supervised learning method of relationship strength estimation on twitter network. Authors used structural graph features from the presence and frequency of small graph motifs on combined weak and strong ties. Abufouda and Zweig [21] estimated social relationship strength based on friendship social network with external interaction using supervised learning model. Authors employed machine learning classification techniques to conduct the link evaluation via edge-proximity based label classification method.
3.6 Social theories-based metrics

There exists numerous studies based on social theories for target of relationship strength estimation. A few reported studies are covered in this section. Sintos and Tsaparas [35] exploited “Strong-Triadic-Closure” Principle to characterize relationship strength on 4 different OSNs. Liberatore and Quijano-Sanchez [23] explored a questionnaire based validation and computational framework for tie strength determination using non-linear factor analysis models for various components related to social media. Pi et al. [31] considered mobile social network and proposed a unified framework to individual’s inter relationship strength. Authors investigated time-aware mobility behavior, co-occurrence diversity, location semantic information, location significance and correlative impact on tie strength estimation. Adali et al. [3] studied statistical features of communication patterns between users on social media. Authors considered reciprocity, attention, latency and assortativity as determinant features to capture contextual information as compared with textual features using Twitter data. Volkovich et al. [38] examined association between interaction strength, spatial inter-space and structural position of users relationships from Google’s Tueti communication network. Authors observed variation of tie strength with nodes k-core index, considering core and periphery structure of studied networks.

4 Tie strength applications

The tie strength metric can be used for diverse range of applications. This section remarks some typical applications including link prediction, recommendation system, ranking groups and individuals, pattern analysis and information diffusion as follows.

- **Group recommendation**: The group recommendation is knowledge based system which provides recommendation to the group having social relationship to support decision making. The tie strength of group members are key factors to characterise and improve the quality of group recommendation system [32].

- **Link prediction applications**: The social relationship strength estimation related to link prediction are among prominent techniques for such applications [32, 48, 29].

- **Strategic game theoretic studies**: The weak ties play a prominent role in determining collective behaviour and maintaining cooperation in evolutionary process of prisoners dilemma game [45].

- **Location based friend prediction**: Increased availability to geographic social networks data and tie strength estimation techniques have made it straightforward to exploit location based social networks for its application to friendship prediction, user behaviour and location recommendation [37].
• **Routing selection:** Social tie strength between nodes in mobile ad-hoc network can be exploited for improvement of optimized link state routing [15].

• **Collaboration prediction in scientific networks:** Tie strength estimation for coauthorship relationship network is a determinant factor for collaboration prediction in such networks [27, 7].

• **Information diffusion and Network control:** The inclusion of weak ties in social networks can disrupt the spreading extent and speed of information, also exploited for network control in mobile social networks [20, 28].

• Other range of applications based on this metric includes crime prediction [4], stock market fluctuation study [9], friendship prediction [37, 11] and pattern analysis [29].

5 **Future challenges**

Future work is imperative to improve and extend the link estimation precision. Online social networks are highly dynamic and a very few studies [5] has been reported to deal with this issue. OSN tie strength prediction can be modeled using and incorporating dynamic online social networks. A large number of methods for tie strength metric in OSNs consider only structural features and attributes, however social theory based methods have been investigated to limited number. More comprehensive work based on both approaches [3, 38] can enhance the accuracy of the metric. The benchmark data sets for the study are inadequate to systematically appraise the performances and outline limitations of the models. The availability of benchmark data-sets for fair evaluation of model is next important step. In online social networks the incomplete or noisy data are usual conditions, therefore more accurate tie estimation methods are required in such settings. Further, practical social networks with multiple relations types and heterogeneous nature of network need to challenge for the tie strength determination goals [1, 31].

6 **Conclusion**

Tie strength estimation has been a primitive problem in the field of social organization and its applications are emerging with the advent of time due to advancement in technologies and availability of system data on online social networks. This paper attempts to deliver a brief review of tie strength estimation techniques with variety of solutions from related researches. The fundamental concept of interaction strength is categorized and classified related to the state-of-the-art in tie strength computing. Tie strength metric estimation based on topological features and users context related machine learning techniques are
mainly presented in the paper. Finally, the real time applications are acknowledged and an excellent direction to future challenges are addressed which could resolve the current research issues related to tie strength computing.

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