In [1]:
```
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
from scipy.stats import zscore
from sklearn.preprocessing import MinMaxScaler, OneHotEncoder
from sklearn.decomposition import PCA
import numpy as np
from sklearn.ensemble import RandomForestClassifier
from sklearn.feature_selection import SelectFromModel
from sklearn.preprocessing import StandardScaler
from sklearn.ensemble import RandomForestClassifier
from sklearn.feature_selection import SelectFromModel
from scipy import stats
from sklearn.decomposition import PCA
from scipy.stats import chi2_contingency
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LogisticRegression
from sklearn.preprocessing import LabelEncoder
from sklearn.metrics import classification_report, accuracy_score
from sklearn.preprocessing import PolynomialFeatures
from sklearn.tree import DecisionTreeClassifier
from sklearn.ensemble import RandomForestClassifier, GradientBoostin
from sklearn.svm import SVC
from sklearn.neural_network import MLPClassifier
from sklearn.metrics import accuracy_score, classification_report
from sklearn.model_selection import cross_val_score
from xgboost import XGBClassifier
from sklearn.preprocessing import StandardScaler
from sklearn.decomposition import PCA
from sklearn.cluster import KMeans, DBSCAN
from sklearn.metrics import silhouette_score
from sklearn.ensemble import IsolationForest
from sklearn.neighbors import LocalOutlierFactor
import warnings
from sklearn.neighbors import NearestNeighbors
from sklearn.manifold import TSNE
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import pairwise_distances_argmin_min
import joblib
```

In [2]:
```
# Suppress warnings
warnings.filterwarnings("ignore")
```

In [3]:
```
# Load the cleaned dataset
df = pd.read_csv("Network_anomaly_data.csv")

# Check the first few rows of the data
print(df.head())

# Get general information about the dataset
print(df.info())
```

```
   duration protocoltype   service flag  srcbytes  dstbytes  land  
\
0         0          tcp  ftp_data   SF       491         0     0   
1         0          udp     other   SF       146         0     0   
2         0          tcp   private   S0         0         0     0   
3         0          tcp      http   SF       232      8153     0   
4         0          tcp      http   SF       199       420     0   

   wrongfragment  urgent  hot  ...  dsthostsamesrvrate  dsthostdif
fsrvrate  \
0              0       0    0  ...                0.17              
0.03   
1              0       0    0  ...                0.00              
0.60   
2              0       0    0  ...                0.10              
0.05   
3              0       0    0  ...                1.00              
0.00   
4              0       0    0  ...                1.00              
0.00   

   dsthostsamesrcportrate  dsthostsrvdiffhostrate  dsthostserrorra
te  \
0                    0.17                    0.00                 0.
00   
1                    0.88                    0.00                 0.
00   
2                    0.00                    0.00                 1.
00   
3                    0.03                    0.04                 0.
03   
4                    0.00                    0.00                 0.
00   

   dsthostsrvserrorrate  dsthostrerrorrate  dsthostsrvrerrorrate 
attack  \
0                  0.00                0.05                  0.00  
normal   
1                  0.00                0.00                  0.00  
normal   
2                  1.00                0.00                  0.00  
neptune   
3                  0.01                0.00                  0.01  
normal   
4                  0.00                0.00                  0.00  
normal   

   lastflag  
0        20  
1        15  
2        19  
3        21  
4        21  
```

```
[5 rows x 43 columns]
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 125973 entries, 0 to 125972
Data columns (total 43 columns):
 #   Column                 Non-Null Count   Dtype
---  ------                 --------------   -----
 0   duration               125973 non-null  int64

 1   protocoltype           125973 non-null  object
 2   service                125973 non-null  object
 3   flag                   125973 non-null  object
 4   srcbytes               125973 non-null  int64
 5   dstbytes               125973 non-null  int64
 6   land                   125973 non-null  int64
 7   wrongfragment          125973 non-null  int64
 8   urgent                 125973 non-null  int64
 9   hot                    125973 non-null  int64
 10  numfailedlogins        125973 non-null  int64
 11  loggedin               125973 non-null  int64
 12  numcompromised         125973 non-null  int64
 13  rootshell              125973 non-null  int64
 14  suattempted            125973 non-null  int64
 15  numroot                125973 non-null  int64
 16  numfilecreations       125973 non-null  int64
 17  numshells              125973 non-null  int64
 18  numaccessfiles         125973 non-null  int64
 19  numoutboundcmds        125973 non-null  int64
 20  ishostlogin            125973 non-null  int64
 21  isguestlogin           125973 non-null  int64
 22  count                  125973 non-null  int64
 23  srvcount               125973 non-null  int64
 24  serrorrate             125973 non-null  float64
 25  srvserrorrate          125973 non-null  float64
 26  rerrorrate             125973 non-null  float64
 27  srvrerrorrate          125973 non-null  float64
 28  samesrvrate            125973 non-null  float64
 29  diffsrvrate            125973 non-null  float64
 30  srvdiffhostrate        125973 non-null  float64
 31  dsthostcount           125973 non-null  int64
 32  dsthostsrvcount        125973 non-null  int64
 33  dsthostsamesrvrate     125973 non-null  float64
 34  dsthostdiffsrvrate     125973 non-null  float64
 35  dsthostsamesrcportrate 125973 non-null  float64
 36  dsthostsrvdiffhostrate 125973 non-null  float64
 37  dsthostserrorrate      125973 non-null  float64
 38  dsthostsrvserrorrate   125973 non-null  float64
 39  dsthostrerrorrate      125973 non-null  float64
 40  dsthostsrvrerrorrate   125973 non-null  float64
 41  attack                 125973 non-null  object
 42  lastflag               125973 non-null  int64
dtypes: float64(15), int64(24), object(4)
memory usage: 41.3+ MB
```

In [4]:
```
# Display missing values before handling
print("Missing values before handling:")
print(df.isnull().sum())
```

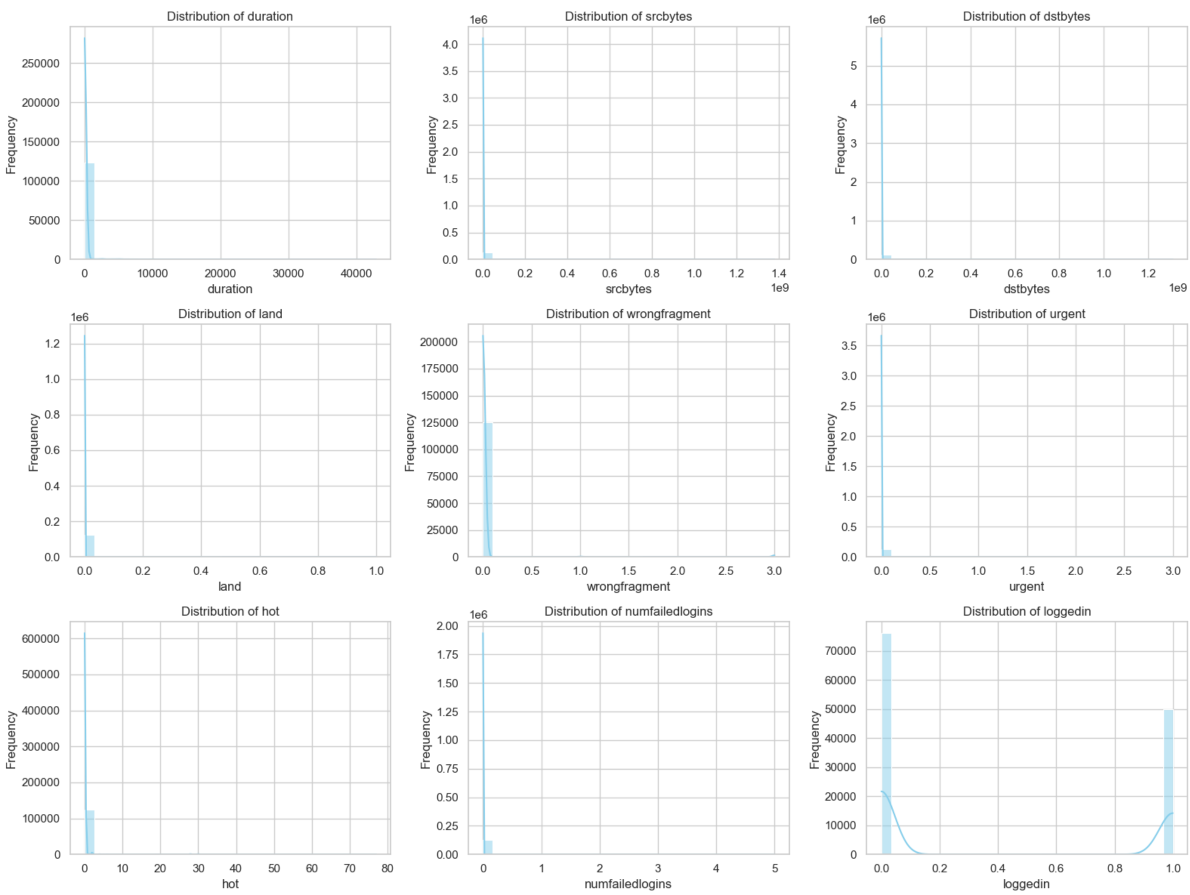
```
Missing values before handling:
duration                  0
protocoltype              0
service                   0
flag                      0
srcbytes                  0
dstbytes                  0
land                      0
wrongfragment             0
urgent                    0
hot                       0
numfailedlogins           0
loggedin                  0
numcompromised            0
rootshell                 0
suattempted               0
numroot                   0
numfilecreations          0
numshells                 0
numaccessfiles            0
numoutboundcmds           0
ishostlogin               0
isguestlogin              0
count                     0
srvcount                  0
serrorrate                0
srvserrorrate             0
rerrorrate                0
srvrerrorrate             0
samesrvrate               0
diffsrvrate               0
srvdiffhostrate           0
dsthostcount              0
dsthostsrvcount           0
dsthostsamesrvrate        0
dsthostdiffsrvrate        0
dsthostsamesrcportrate    0
dsthostsrvdiffhostrate    0
dsthostserrorrate         0
dsthostsrvserrorrate      0
dsthostrerrorrate         0
dsthostsrvrerrorrate      0
attack                    0
lastflag                  0
dtype: int64
```

In [5]:
```
# Separate numerical and categorical columns
numerical_columns = df.select_dtypes(include=['float64', 'int64']).
categorical_columns = df.select_dtypes(include=['object']).columns

# Replace missing values in numerical columns with the median
for col in numerical_columns:
    df[col].fillna(df[col].median(), inplace=True)

# Replace missing values in categorical columns with the most frequ
for col in categorical_columns:
    df[col].fillna(df[col].mode()[0], inplace=True)
```

In [6]:
```
# Display missing values after handling
print("\nMissing values after handling:")
print(df.isnull().sum())
```

```
Missing values after handling:
duration                     0
protocoltype                 0
service                      0
flag                         0
srcbytes                     0
dstbytes                     0
land                         0
wrongfragment                0
urgent                       0
hot                          0
numfailedlogins              0
loggedin                     0
numcompromised               0
rootshell                    0
suattempted                  0
numroot                      0
numfilecreations             0
numshells                    0
numaccessfiles               0
numoutboundcmds              0
ishostlogin                  0
isguestlogin                 0
count                        0
srvcount                     0
serrorrate                   0
srvserrorrate                0
rerrorrate                   0
srvrerrorrate                0
samesrvrate                  0
diffsrvrate                  0
srvdiffhostrate              0
dsthostcount                 0
dsthostsrvcount              0
dsthostsamesrvrate           0
dsthostdiffsrvrate           0
dsthostsamesrcportrate       0
dsthostsrvdiffhostrate       0
dsthostserrorrate            0
dsthostsrvserrorrate         0
dsthostrerrorrate            0
dsthostsrvrerrorrate         0
attack                       0
lastflag                     0
dtype: int64
```

In [7]:
```
# Set plot style
sns.set(style="whitegrid")

# Function to plot the distribution of numeric features
def plot_feature_distributions(data, feature_columns):
    n_cols = 3
    n_rows = (len(feature_columns) + n_cols - 1) // n_cols
    plt.figure(figsize=(16, n_rows * 4))

    for i, feature in enumerate(feature_columns, 1):
        plt.subplot(n_rows, n_cols, i)
        sns.histplot(data[feature], kde=True, bins=30, color="skybl
        plt.title(f"Distribution of {feature}")
        plt.xlabel(feature)
        plt.ylabel("Frequency")

    plt.tight_layout()
    plt.show()

# Select numeric columns for distribution analysis
numeric_columns = df.select_dtypes(include=['int64', 'float64']).co
plot_feature_distributions(df, numeric_columns[:9])  # Plot for the
```



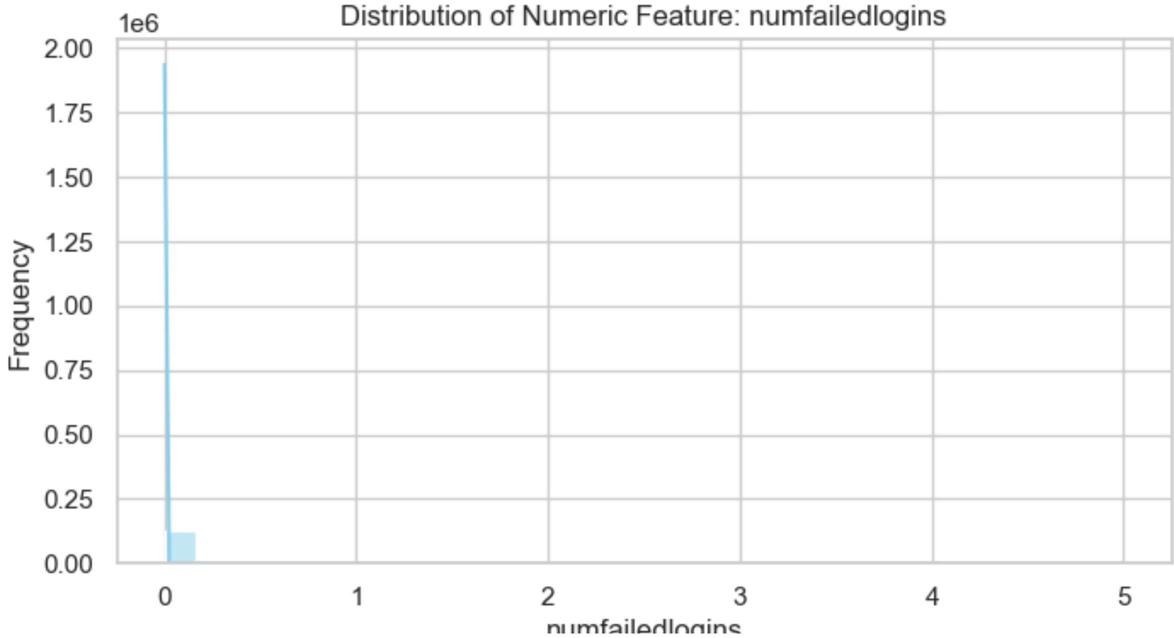
Observations:

Features like duration, srcbytes, and dstbytes have highly skewed distributions, likely influenced by extreme outliers or infrequent high values. Binary features such as land and urgent show a discrete distribution. Some features, like wrongfragment, have a significant number of zero entries, indicating sparsity.

In [8]:
```
def plot_distributions(data):
    # Separate numeric and categorical columns
    numeric_columns = data.select_dtypes(include=['int64', 'float64
    categorical_columns = data.select_dtypes(include=['object', 'ca

    # Plot distributions for numeric features
    for column in numeric_columns:
        plt.figure(figsize=(8, 4))
        sns.histplot(data[column], kde=True, bins=30, color="skyblu
        plt.title(f"Distribution of Numeric Feature: {column}")
        plt.xlabel(column)
        plt.ylabel("Frequency")
        plt.show()

    # Plot distributions for categorical features
    for column in categorical_columns:
        plt.figure(figsize=(8, 4))
        sns.countplot(data=data, x=column, palette="viridis")
        plt.title(f"Distribution of Categorical Feature: {column}")
        plt.xlabel(column)
        plt.ylabel("Count")
        plt.xticks(rotation=45)
        plt.show()
```

In [9]:
```
# Call the function to visualize all feature distributions
plot_distributions(df)
```

hot

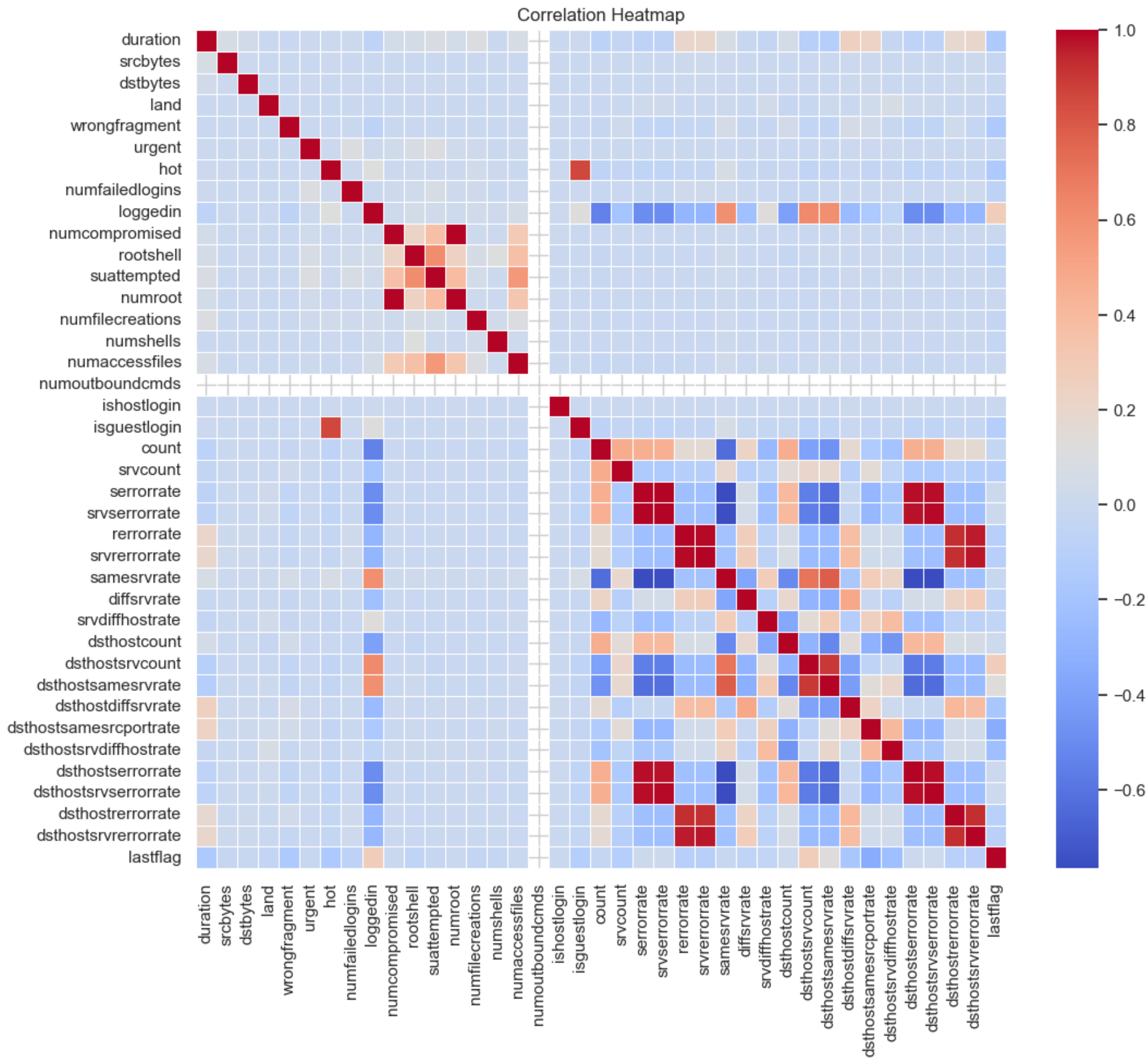


Corelation

To identify highly correlated features in your dataset and drop the ones that are redundant, we can calculate the correlation matrix and use a threshold to decide which features to drop.

In [10]:
```
def correlation_analysis(data):
    # Compute the correlation matrix
    # Identify numerical columns to scale/normalize
    numerical_columns = data.select_dtypes(include=['float64', 'int
    corr_matrix = data[numerical_columns].corr()

    # Plot the heatmap
    plt.figure(figsize=(12, 10))
    sns.heatmap(corr_matrix, annot=False, cmap="coolwarm", fmt='.2f
    plt.title("Correlation Heatmap")
    plt.show()

    # Return the correlation matrix for further analysis
    return corr_matrix
```

In [11]:
```
# Call the function for correlation analysis
correlation_matrix = correlation_analysis(df)
```



In [12]:
```
# Check for duplicates
print(f"Number of duplicates before removal: {df.duplicated().sum()

# Remove duplicates
df_cleaned = df.drop_duplicates()

# Verify if duplicates are removed
print(f"Number of duplicates after removal: {df_cleaned.duplicated(
```

```
Number of duplicates before removal: 0
Number of duplicates after removal: 0
```

In [13]:
```
categorical_columns = ['protocoltype', 'service', 'flag']

# Dictionary to store mappings
label_encoders = {}
label_mappings = {}

# Apply Label Encoding and store mappings
for col in categorical_columns:
    le = LabelEncoder()
    df[col] = le.fit_transform(df[col])
    label_encoders[col] = le
    label_mappings[col] = {index: label for index, label in enumera

# Print the mappings for each column
for col, mapping in label_mappings.items():
    print(f"Mapping for {col}:")
    for encoded, original in mapping.items():
        print(f"  {encoded} -> {original}")
    print()

# Display the first few rows of the dataset
print("\nEncoded Dataset:")
print(df.head())
```

```
  51 -> remote_job
  52 -> rje
  53 -> shell
  54 -> smtp
  55 -> sql_net
  56 -> ssh
  57 -> sunrpc
  58 -> supdup
  59 -> systat
  60 -> telnet
  61 -> tftp_u
  62 -> tim_i
  63 -> time
  64 -> urh_i
  65 -> urp_i
  66 -> uucp
  67 -> uucp_path
  68 -> vmnet
  69 -> whois
```

In [14]:
```
# Identify numerical columns to scale/normalize
numerical_columns = df.select_dtypes(include=['float64', 'int64']).

# Standardization: Mean = 0, Std Dev = 1
standard_scaler = StandardScaler()
df_standardized = df.copy()
df_standardized[numerical_columns] = standard_scaler.fit_transform(
```

```
# Normalization: Scale to range [0, 1]
minmax_scaler = MinMaxScaler()
df_normalized = df.copy()
df_normalized[numerical_columns] = minmax_scaler.fit_transform(df[n

# Display the transformed datasets
print("Standardized Dataset (first 5 rows):")
print(df_standardized.head())

print("\nNormalized Dataset (first 5 rows):")
print(df_normalized.head())
```

```
Standardized Dataset (first 5 rows):
   duration  protocoltype   service      flag  srcbytes  dstbytes
land  \
0 -0.110249     -0.124706 -0.686785  0.751111 -0.007679 -0.004919
-0.014089
1 -0.110249      2.219312  0.781428  0.751111 -0.007737 -0.004919
-0.014089
2 -0.110249     -0.124706  1.087305 -0.736235 -0.007762 -0.004919
-0.014089
3 -0.110249     -0.124706 -0.442083  0.751111 -0.007723 -0.002891
-0.014089
4 -0.110249     -0.124706 -0.442083  0.751111 -0.007728 -0.004814
-0.014089

   wrongfragment    urgent       hot  ...  dsthostsamesrvrate  \
0      -0.089486 -0.007736 -0.095076  ...           -0.782367
1      -0.089486 -0.007736 -0.095076  ...           -1.161030
2      -0.089486 -0.007736 -0.095076  ...           -0.938287
3      -0.089486 -0.007736 -0.095076  ...            1.066401
4      -0.089486 -0.007736 -0.095076  ...            1.066401

   dsthostdiffsrvrate  dsthostsamesrcportrate  dsthostsrvdiffhostr
ate  \
0           -0.280282                0.069972               -0.289
103
1            2.736852                2.367737               -0.289
103
2           -0.174417               -0.480197               -0.289
103
3           -0.439078               -0.383108                0.066
252
4           -0.439078               -0.480197               -0.289
103

   dsthostserrorrate  dsthostsrvserrorrate  dsthostrerrorrate  \
0          -0.639532             -0.624871          -0.224532
1          -0.639532             -0.624871          -0.387635
2           1.608759              1.618955          -0.387635
3          -0.572083             -0.602433          -0.387635
4          -0.639532             -0.624871          -0.387635

   dsthostsrvrerrorrate   attack  lastflag
```

```
0             -0.376387   normal  0.216426
1             -0.376387   normal -1.965556
2             -0.376387  neptune -0.219970
3             -0.345084   normal  0.652823
4             -0.376387   normal  0.652823

[5 rows x 43 columns]

Normalized Dataset (first 5 rows):
   duration  protocoltype   service  flag      srcbytes      dstby
tes  land  \
0       0.0           0.5  0.289855   0.9  3.558064e-07  0.000000e
+00   0.0
1       0.0           1.0  0.637681   0.9  1.057999e-07  0.000000e
+00   0.0
2       0.0           0.5  0.710145   0.5  0.000000e+00  0.000000e
+00   0.0
3       0.0           0.5  0.347826   0.9  1.681203e-07  6.223962e
-06   0.0
4       0.0           0.5  0.347826   0.9  1.442067e-07  3.206260e

-07   0.0

   wrongfragment  urgent  hot  ...  dsthostsamesrvrate  dsthostdif
fsrvrate  \
0            0.0     0.0  0.0  ...                0.17
0.03
1            0.0     0.0  0.0  ...                0.00
0.60
2            0.0     0.0  0.0  ...                0.10
0.05
3            0.0     0.0  0.0  ...                1.00
0.00
4            0.0     0.0  0.0  ...                1.00
0.00

   dsthostsamesrcportrate  dsthostsrvdiffhostrate  dsthostserrorra
te  \
0                    0.17                    0.00               0.
00
1                    0.88                    0.00               0.
00
2                    0.00                    0.00               1.
00
3                    0.03                    0.04               0.
03
4                    0.00                    0.00               0.
00

   dsthostsrvserrorrate  dsthostrerrorrate  dsthostsrvrerrorrate
attack  \
0                  0.00               0.05                  0.00
normal
1                  0.00               0.00                  0.00
```

```
normal
2                  1.00               0.00                 0.00
neptune
3                  0.01               0.00                 0.01
normal
4                  0.00               0.00                 0.00
normal

   lastflag
0  0.952381
1  0.714286
2  0.904762
3  1.000000
4  1.000000

[5 rows x 43 columns]
```

Explanation of Changes:

Dropping Only One Feature from Each Pair:

For each correlated pair, only the first feature (i.e., pair[0]) is added to the correlated_features set, ensuring that only one feature from each correlated pair is dropped.

Set Data Structure for Features to Drop:

A set is used to ensure that each feature is only added once, even if it appears in multiple correlated pairs.

In [15]:

```
# Select only numeric fields
numeric_df = df.select_dtypes(include=[np.number])

# Calculate the correlation matrix
correlation_matrix = numeric_df.corr()

# Set a threshold for correlation (e.g., 0.9)
threshold = 0.9

# Initialize a list to store correlated column pairs
correlated_pairs = []

# Find highly correlated features
for i in range(len(correlation_matrix.columns)):
    for j in range(i):
        if abs(correlation_matrix.iloc[i, j]) > threshold:  # Check
            colname1 = correlation_matrix.columns[i]
            colname2 = correlation_matrix.columns[j]
            correlated_pairs.append((colname1, colname2))

# Print correlated column pairs
```

```
if correlated_pairs:
    print("Highly correlated column pairs (correlation > 0.9):")
    for pair in correlated_pairs:
        print(f"{pair[0]} and {pair[1]}")
else:
    print("No highly correlated column pairs found.")

# Initialize a set to keep track of features to drop
correlated_features = set()

# Keep only the first feature of each correlated pair (drop the sec
for pair in correlated_pairs:
    correlated_features.add(pair[0])  # Add only the first feature

# Drop the selected features from the original dataframe
df = df.drop(columns=correlated_features)

# Output the dropped features
print(f"\nDropped features due to high correlation: {correlated_fea
```

```
Highly correlated column pairs (correlation > 0.9):
numroot and numcompromised
srvserrorrate and serrorrate
srvrerrorrate and rerrorrate
dsthostserrorrate and serrorrate
dsthostserrorrate and srvserrorrate
dsthostsrvserrorrate and serrorrate
dsthostsrvserrorrate and srvserrorrate
dsthostsrvserrorrate and dsthostserrorrate
dsthostrerrorrate and rerrorrate
dsthostrerrorrate and srvrerrorrate
dsthostsrvrerrorrate and rerrorrate
dsthostsrvrerrorrate and srvrerrorrate
dsthostsrvrerrorrate and dsthostrerrorrate

Dropped features due to high correlation: {'dsthostrerrorrate', 'n
umroot', 'dsthostsrvrerrorrate', 'dsthostserrorrate', 'srvrerrorra
te', 'dsthostsrvserrorrate', 'srvserrorrate'}
```

In [16]:
```
df.head()
```

Out[16]:

	duration	protocoltype	service	flag	srcbytes	dstbytes	land	wrongfragment	urgent	l
0	0	1	20	9	491	0	0	0	0	
1	0	2	44	9	146	0	0	0	0	
2	0	1	49	5	0	0	0	0	0	
3	0	1	24	9	232	8153	0	0	0	
4	0	1	24	9	199	420	0	0	0	

5 rows × 36 columns

In [17]:
```
# Creating Interaction Features (combining numerical features)
df['src_dst_bytes_interaction'] = df['srcbytes'] * df['dstbytes']
df['num_failed_logins_hot_interaction'] = df['numfailedlogins'] * d
df['num_compromised_su_interaction'] = df['numcompromised'] * df['s

# Aggregated Features: Summary statistics over groups of features
df['total_data_transfer'] = df['srcbytes'] + df['dstbytes']  # Tota
df['total_access_operations'] = df['numfilecreations'] + df['numshe



# Drop any features that you may not need
df = df.drop(columns=['srcbytes', 'dstbytes', 'attack'])  # Droppin
```

In [18]:
```
df.head()
```

Out[18]:

	duration	protocoltype	service	flag	land	wrongfragment	urgent	hot	numfailedlogins
0	0	1	20	9	0	0	0	0	0
1	0	2	44	9	0	0	0	0	0
2	0	1	49	5	0	0	0	0	0
3	0	1	24	9	0	0	0	0	0
4	0	1	24	9	0	0	0	0	0

5 rows × 38 columns

In [19]:
```
# Preprocessing
scaler = StandardScaler()
scaled_data = scaler.fit_transform(df)
```

In [20]:
```
# Dimensionality Reduction (PCA)
pca = PCA(n_components=0.95)  # Retain 95% variance
reduced_data = pca.fit_transform(scaled_data)
print(f"Reduced data shape: {reduced_data.shape}")
```

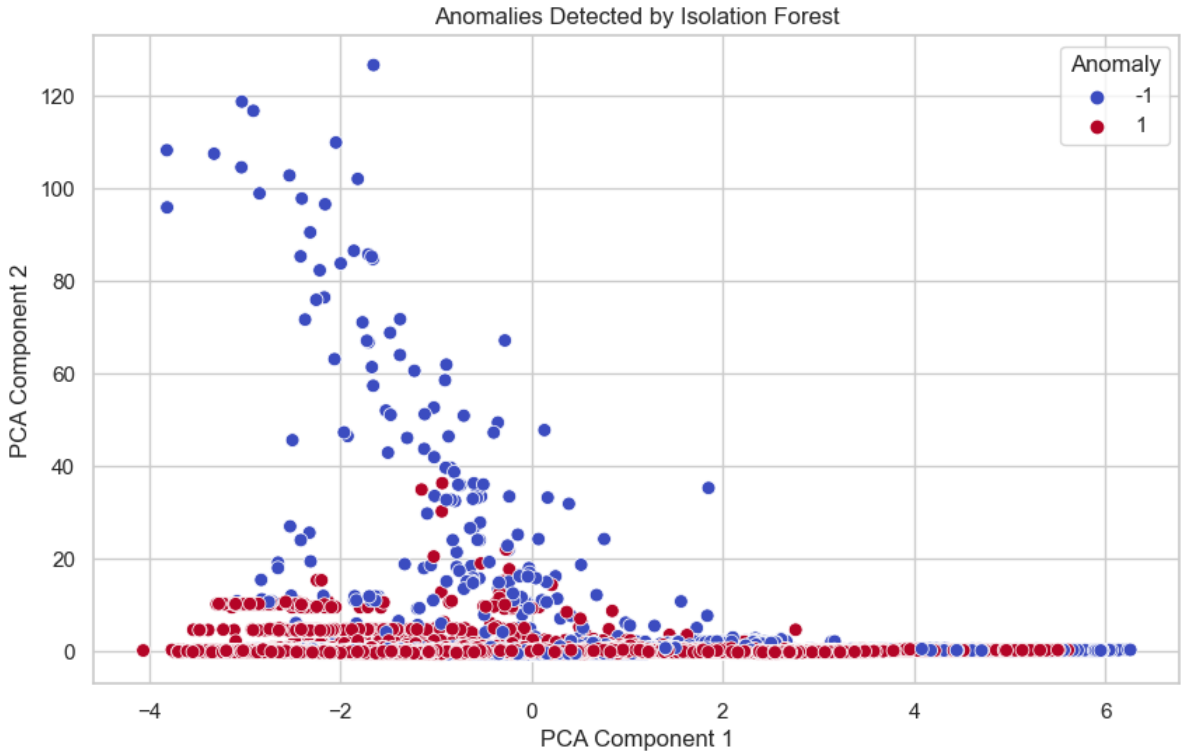
```
Reduced data shape: (125973, 27)
```

In [21]:
```
# Visualize Results (PCA-reduced 2D data)
tsne = PCA(n_components=2)
data_2d = tsne.fit_transform(reduced_data)
```

In [22]:
```
# Anomaly Detection - Isolation Forest
iso_forest = IsolationForest(contamination=0.05, random_state=42)
anomaly_labels_iso = iso_forest.fit_predict(scaled_data)
print(f"Number of clusters (Isolation Forest): {len(set(anomaly_lab
print(f"Number of anomalies detected: {(anomaly_labels_iso == -1).s
```

```
Number of clusters (Isolation Forest): 1
Number of anomalies detected: 6298
```

In [23]:
```
# Plot Anomalies Detected by Isolation Forest
plt.figure(figsize=(10, 6))
sns.scatterplot(x=data_2d[:, 0], y=data_2d[:, 1], hue=anomaly_label
plt.title("Anomalies Detected by Isolation Forest")
plt.xlabel("PCA Component 1")
plt.ylabel("PCA Component 2")
plt.legend(title="Anomaly")
plt.show()
```



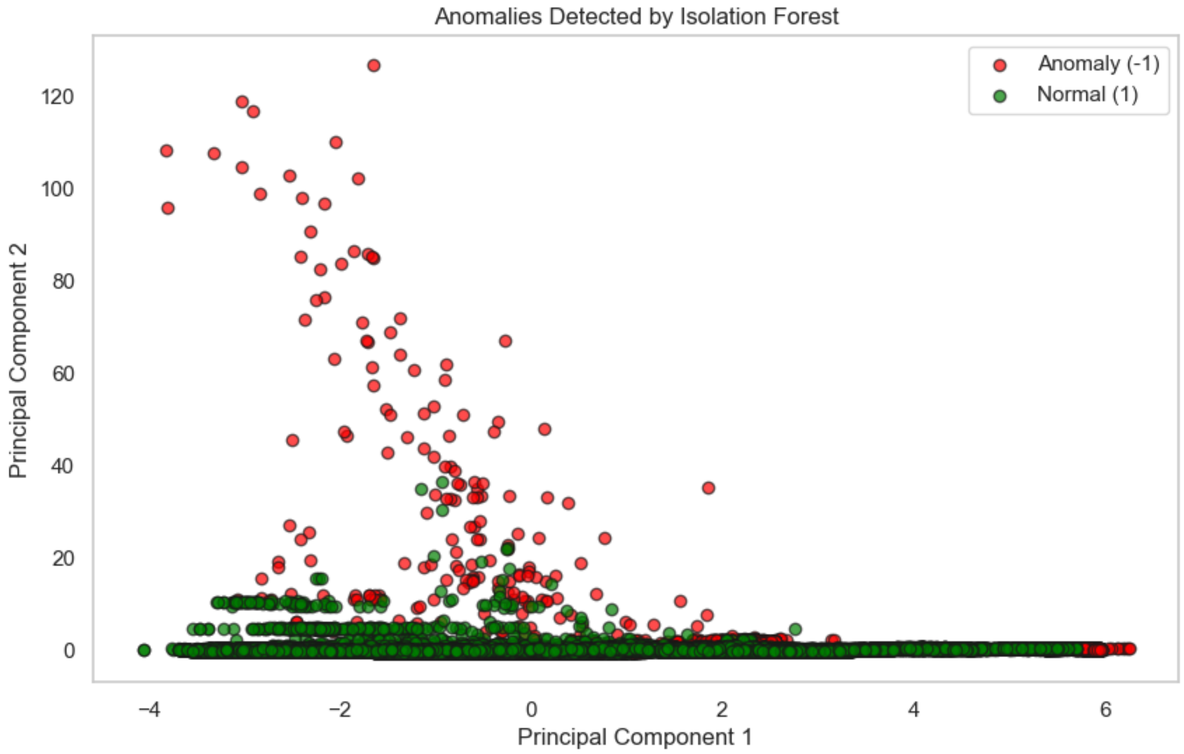
In [24]:
```
# Save the model to a file
joblib.dump(iso_forest, "isolation_forest_model.joblib")
print("Model saved successfully.")
```

```
Model saved successfully.
```

In [27]:
```
# Load the model from the file
iso_forest_loaded = joblib.load("isolation_forest_model.joblib")
print("Model loaded successfully.")

# Predict anomalies
anomaly_labels = iso_forest_loaded.predict(scaled_data)

# Count and summarize anomalies
num_anomalies = (anomaly_labels == -1).sum()
num_normal = (anomaly_labels == 1).sum()

print(f"Total anomalies detected: {num_anomalies}")
print(f"Total normal instances: {num_normal}")
```

```
Model loaded successfully.
Total anomalies detected: 6298
Total normal instances: 119675
```

In [34]:
```
# Separate anomalies and normal instances
anomalies = reduced_data[anomaly_labels == -1]
normal = reduced_data[anomaly_labels == 1]

# Plot anomalies and normal instances separately
plt.figure(figsize=(10, 6))
plt.scatter(anomalies[:, 0], anomalies[:, 1], c='red', label='Anoma
plt.scatter(normal[:, 0], normal[:, 1], c='green', label='Normal (1

# Add title, labels, and legend
plt.title("Anomalies Detected by Isolation Forest")
plt.xlabel("Principal Component 1")
plt.ylabel("Principal Component 2")
plt.legend(loc="best")  # Proper legend
plt.grid()
plt.show()
```



In [ ]: